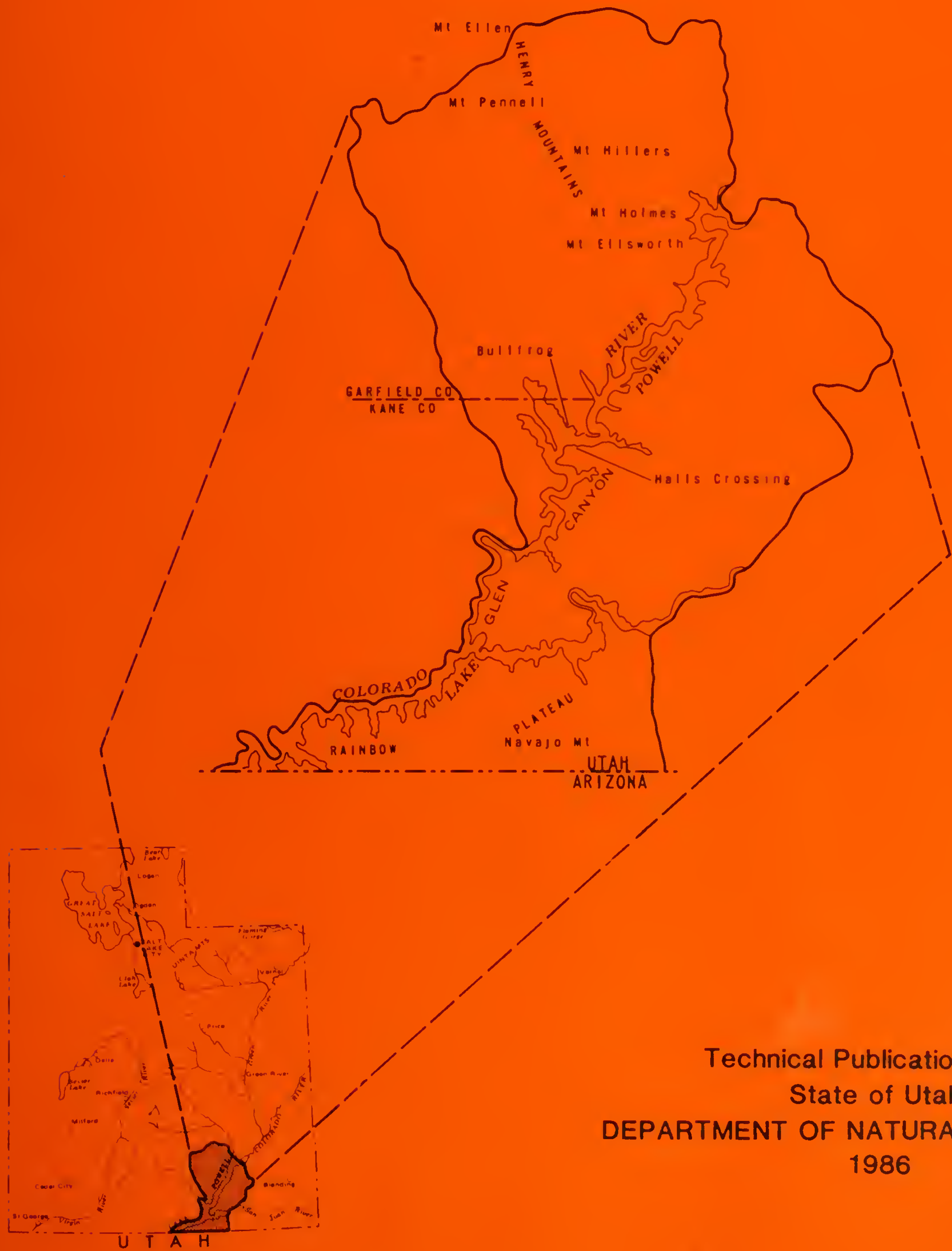
GLCA

GROUND-WATER CONDITIONS IN THE LAKE POWELL AREA, UTAH



Technical Publication No. 84
State of Utah
DEPARTMENT OF NATURAL RESOURCES
1986

NORMAN H. BANGERTER
Governor

This report was prepared as a part of the Statewide cooperative water-resource investigation program administered jointly by the Utah Department of Natural Resources, Division of Water Rights and the United States Geological Survey. The program is conducted to meet the water administration and water-resource data needs of the State, as well as the water information needs of many units of government and the general public.

Dee C. Hansen
Executive Director
Department of Natural Resources

Robert L. Morgan
State Engineer
Division of Water Rights

Copies available at
Utah Department of Natural Resources
Division of Water Rights
1636 West North Temple, Room 220
Salt Lake City, Utah 84116

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

Technical Publication No. 84

GROUND-WATER CONDITIONS IN THE LAKE POWELL AREA, UTAH

by

Paul J. Blanchard
Hydrologist, U.S. Geological Survey

Prepared by
the United States Geological Survey
in cooperation with
The Utah Department of Natural Resources
Division of Water Rights

1986

CONTENTS

ILLUSTRATIONS
[Plates are in pocket]

TABLES

CONVERSION FACTORS AND RELATED INFORMATION

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
acre	0.4047	square hectometer
	0.004047	square kilometer
acre-foot	0.001233	cubic hectometer
	1233.	cubic meter
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
foot per day	0.3048	meter per day
foot squared per day	0.0929	meter squared per day
gallon per minute	0.06309	liter per second
gallon per minute per foot	0.2070	liter per second per meter
inch	25.40	millimeter
	2.540	centimeter
mile	1.609	kilometer
square mile	2.590	square kilometer

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter of water). One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million.

Chemical concentration in terms of ionic interacting values is given in milliequivalents per liter. Milliequivalents per liter is numerically equal to equivalents per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8(°C) + 32$$

GROUND-WATER CONDITIONS IN THE LAKE POWELL AREA, UTAH

by Paul J. Blanchard
Hydrologist, U.S. Geological Survey

ABSTRACT

The Lake Powell area comprises about 2,450 square miles in south-central Utah. It is subdivided into three geographical areas by the Colorado and San Juan Rivers. The Henry Mountains area is north of the Colorado River, the Navajo Mountain area is south of the San Juan River, and the third area is between the Colorado and San Juan Rivers.

The Entrada, Navajo, and Wingate Sandstones contain the principal aquifers in the Lake Powell area. In terms of potential for development, the Navajo is the most significant of the three aquifers. The estimated transmissivity of the Glen Canyon Group (the Navajo and Wingate Sandstones, and the Kayenta Formation which lies between the Navajo and Wingate) ranges from about 1,000 to 3,750 feet squared per day in the Henry Mountains area, from about 300 to 2,000 feet squared per day in the area between the Colorado and San Juan Rivers, and generally from about 4 to 40 feet squared per day in the Navajo Mountain area. The Moenave Formation is part of the Glen Canyon Group, but it is present only in part of the Navajo Mountain area. No wells are completed in the Moenave and no springs discharge from it.

Recharge to the formations of the Glen Canyon Group occurs in all three subdivisions of the study area by direct infiltration of precipitation, by infiltration from ephemeral streams, and by infiltration of water stored in dune sand where it overlies rocks of the Glen Canyon Group. In the Henry Mountains and Navajo Mountain areas, recharge also occurs by downward movement of water from overlying formations on the flanks of the Henry Mountains and Navajo Mountain, where those formations are significantly fractured.

Discharge from the Glen Canyon Group generally occurs via small springs and seeps discharging less than 10 gallons per minute to Glen Canyon, the canyon of the San Juan River, or to tributary canyons near their mouths. Annual discharge is about 1,000 acre-feet in the Henry Mountains area, about 1,000 acre-feet in the area between the Colorado and San Juan Rivers, and about 1,500 acre-feet in the Navajo Mountain area.

Ground water in the principal aquifers was fresh wherever it was sampled in the Lake Powell area. In the Henry Mountains area, the significant cations generally are magnesium, calcium, and sodium. In the area between the Colorado and San Juan Rivers and in the Navajo Mountain area, the significant cations generally are calcium and magnesium. Bicarbonate generally is the only significant anion throughout the study area.

Concentrations of radionuclides in ground water are larger in the Henry Mountains area than in the area between the Colorado and San Juan Rivers. The larger concentrations are most likely due to the presence of the uranium-rich Salt Wash Member of the Morrison Formation, to mining and processing of the Salt Wash Member, or to both factors.

To predict the effects of large-scale withdrawals of ground water from the Navajo Sandstone, the effects of a hypothetical withdrawal plan in the Henry Mountains area have been estimated. The plan involves the withdrawal of 40,000 acre-feet per year, about the volume of water required for cooling by a large thermoelectric powerplant, from the Navajo Sandstone near the townsite of Ticaboo. At this withdrawal rate, the Navajo Sandstone at the pumping site would be completely drained in less than 10 years. If withdrawal could continue longer than 10 years without dewatering the aquifer at the pumping site, drawdown would be about 230 feet at a distance of about 19 miles from the pumping site after about 50 years. Due to the small amount of recharge to and discharge from the Navajo Sandstone in the area, most of the water would come from storage rather than from diverted natural discharge.

INTRODUCTION

Purpose and Scope

This report presents results of investigation of ground-water conditions in part of the Lake Powell area of south-central Utah. The area contains known and potential reserves of oil, gas, coal, and uranium. Uranium is presently (1984) being mined and a uranium mill is located near the townsite of Ticaboo. Further development of energy resources would require additional development of water resources. Increased use of parts of the area for recreation places a second demand on its water resources.

The purpose of this study was to provide Federal, State, and local water managers, water users, and other interested parties with information concerning the availability and quality of ground water in principal aquifers in the area--the Navajo, Wingate, and Entrada Sandstones--with emphasis on the Navajo Sandstone. This study was made by the U.S. Geological Survey in cooperation with the Utah Department of Natural Resources, Division of Water Rights. Field work was done during August 1982 and March through November 1983.

Field work consisted of an inventory of wells and a partial inventory of springs. Water samples were collected where practicable and sent to the Denver Central Laboratory of the U.S. Geological Survey for chemical analysis. Shallow core samples and outcrop samples of the aquifers were collected, and hydrologic characteristics of the samples were determined by Core Laboratories, Inc., Denver, Colorado.

Previous Investigations

Several investigators have made reconnaissance appraisals of ground water in parts of the Lake Powell area, and others have made water-supply investigations at specific sites in the area. Gregory made appraisals of the area south of the San Juan River (1916) and the area between the Colorado and San Juan Rivers (1938). During the late 1940's the U.S. Geological Survey began a comprehensive investigation of the ground-water resources of the Navajo and Hopi Indian Reservations, including the Navajo Mountain area of this study. Reports from that investigation which pertain to the Navajo Mountain area include Brown and others (1949), Davis and others (1963), Kister and Hatchett (1963), McGavock and others (1966), and Cooley and others (1969).

Miser (1924), and Hunt and others (1953), respectively, briefly commented on the water resources in the canyon of the San Juan River and in the Henry Mountains area.

Iorns and others (1964) compiled records of water resources in the Upper Colorado River Basin, including discharges and chemical analyses of water at selected springs in the Lake Powell area. Iorns and others (1965) reported on the water resources of the Upper Colorado River Basin, with emphasis on surface water. Cooley (1965) inventoried springs in Glen Canyon and the canyon of the San Juan River prior to the inundation of the canyons by Lake Powell. Feltis (1966) compiled information about springs and wells in the entire Lake Powell area as part of a larger study. Goode and Olson (1977) made a reconnaissance appraisal of the water resources in the Henry Mountains area, and Hood (1980) discussed the geology and hydrology of the Navajo Sandstone in the Henry Mountains area.

General Description of the Study Area

The part of the Lake Powell area investigated during this study is located in eastern Garfield County, extreme northeastern Kane County, and southwestern San Juan County, Utah, and comprises about 2,450 square miles (fig. 1). The area is subdivided into three geographical areas by the Colorado and San Juan Rivers (fig. 2). The Henry Mountains area is located north of the Colorado River, the Navajo Mountain area lies south of the San Juan River, and the third area is between the Colorado and San Juan Rivers. The three areas respectively comprise about 1,135, 425, and 890 square miles.

The boundaries of the Lake Powell area primarily are hydrologic boundaries (fig. 2). The Escalante River drainage divide and the Colorado River form the western boundary, and the Fremont and Dirty Devil River drainage divides form the northern and northeastern boundaries. The eastern and southeastern boundaries are the easternmost and southeasternmost extent of the principal aquifers where they are hydrologically significant. The southern boundary is the Utah-Arizona border.

The Lake Powell area is part of the Colorado Plateaus physiographic province (Fenneman, 1931, p. 274-325). The province generally consists of nearly flat-lying sedimentary strata that are deeply incised by major stream systems and interrupted by generally north-south trending monoclines and elongate structural domes and basins. Extrusive and intrusive igneous features are widely scattered throughout the province.

In the Lake Powell area, the strata generally dip to the west at less than five degrees. The most prominent structural features are the Waterpocket monocline along the western border of the area, the Henry Mountains structural basin to the east of the Waterpocket monocline, Balanced Rock anticline between the Colorado and San Juan Rivers, and a series of alternating anticlines and synclines east of Navajo Mountain (pl. 1). Navajo Mountain and the five peaks of the Henry Mountains are the igneous features in the area.

Altitudes in the Lake Powell area range from about 3,700 feet along the shoreline of Lake Powell to 11,522 feet on Mount Ellen. The altitudes of most of the plateaus are below 6,000 feet, with small areas as high as 7,000 feet.

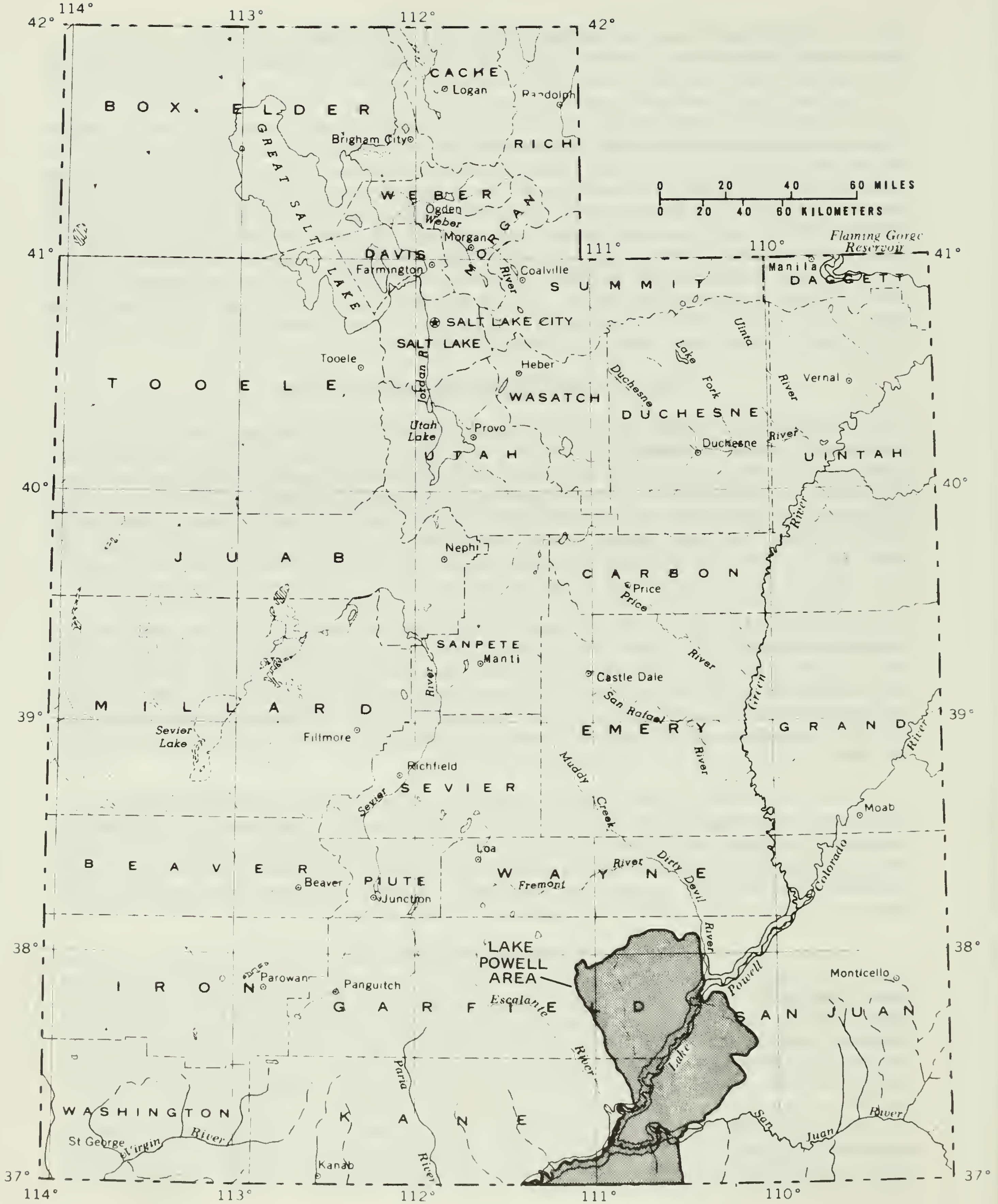


Figure 1.—Location of the Lake Powell area.

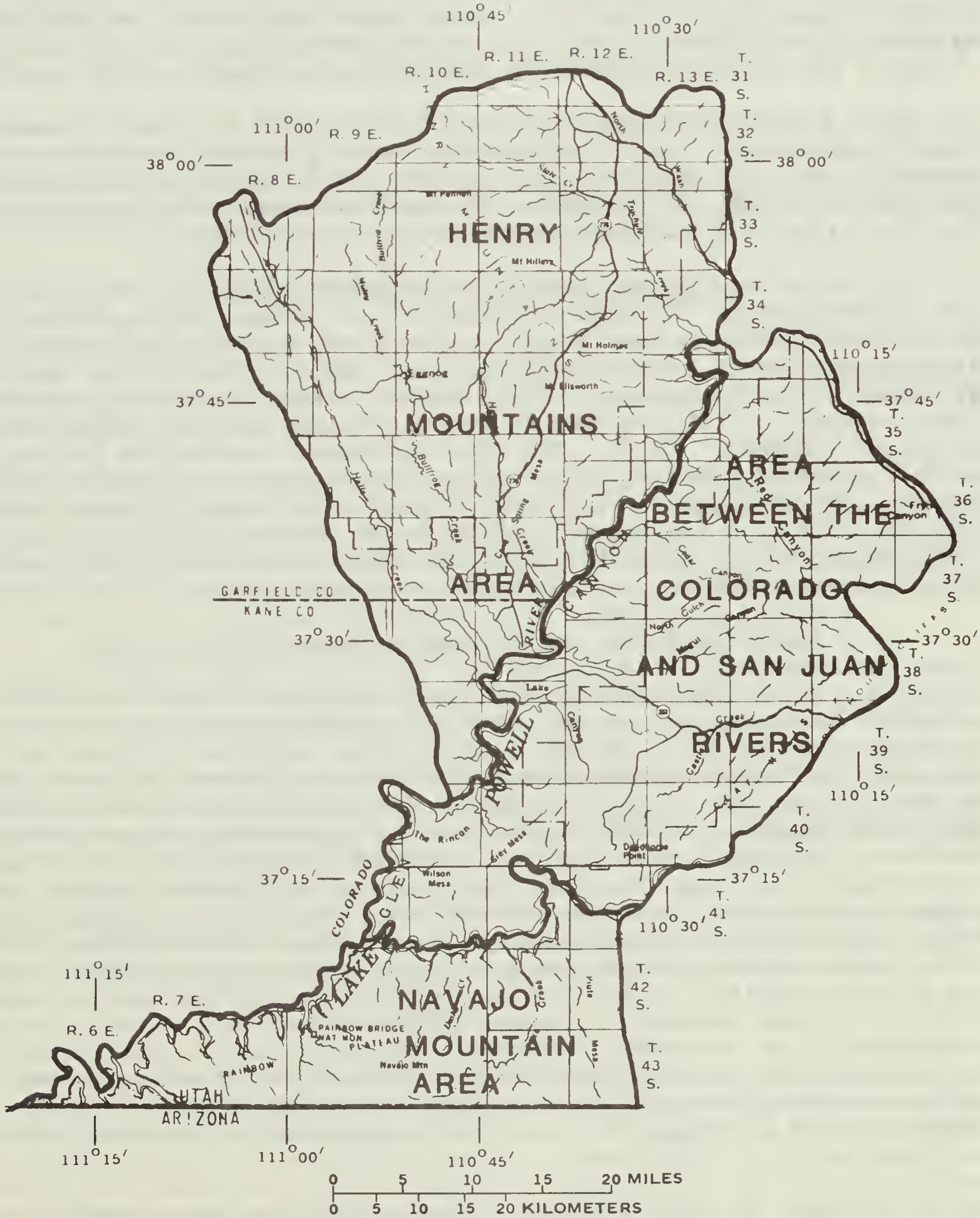


Figure 2.—Subdivisions of the Lake Powell area.

The climate of the Lake Powell area is dry according to the classification of Trewartha (1968, p. 248-250), with annual potential evaporation exceeding annual precipitation. A highland climate (Trewartha, 1968, p. 358-369) exists on the five peaks of the Henry Mountains and on Navajo Mountain. Mean annual temperature is about 55 °F in most of the plateau areas, and less than 45 °F above about 8,000 feet. The two formation classes of vegetation in the area are semidesert in the canyons and on the plateaus, and needleleaf forest in the mountains (Strahler, 1970, p. 235-240).

Most of the land north of the San Juan River is administered by the Federal government (pl. 2). The Glen Canyon National Recreation Area is administered by the National Park Service, and most of the remainder of the land is administered by the Bureau of Land Management. The land south of the San Juan River is administered by the Navajo Indian Tribe.

Population of the Lake Powell area is sparse. Based on 1980 figures from the U.S. Department of Commerce, Bureau of the Census, the population density of the entire area is less than one person per square mile. There are no incorporated areas in the study area and only five centers of population: Bullfrog, Halls Crossing, and Hite Marinas along Lake Powell, the Ticaboo townsite north of Bullfrog Marina, and the Navajo Mountain Trading Post east of Navajo Mountain (pl. 2). The total permanent population for the three marinas is about 250, and an additional 200 residents are present during the summer. The population at the Ticaboo townsite is presently (1984) about 100. When operations were at capacity at the nearby Shootering Canyon Uranium Mill, the population was about 500. Probably fewer than 500 people live at the Navajo Mountain Trading Post and in the surrounding area.

Numbering System for Hydrogeologic-Data Sites in Utah

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well, spring, or other site, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated by the upper case letters A, B, C, and D, indicating, respectively, the northeast, northwest, southwest, and southeast quadrants. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. For half townships or ranges the letter "T" or "R", respectively, precedes the parentheses. The number after the parentheses indicates the section and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section--generally 10 acres[1]. The letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the 10-acre tract; the letter "S" preceding the serial number denotes a spring. If a well or spring cannot be located within a 10-

---

[1]Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

acre tract, one or two location letters are used and the serial number is omitted. Thus (D-36-12)18bbd-1 designates the first well constructed or visited in the SE1/4NW1/4NW1/4 sec. 18, T. 36 S., R. 12 E., and (D-42-9)1acb-S1 designates the first spring inventoried in the NW1/4SW1/4NE1/4 sec. 1, T. 42 S., R. 9 E. The numbering system without serial numbers is used to show the location of data sites other than wells and springs. Such data sites include locations where geologic cores and outcrop samples were collected. The numbering system is illustrated in figure 3.

Locally, there is some conflict between locations based on geographic features and those based on the land-survey system because of the small scale of the maps used in this report. Where such conflict exists, data sites have been plotted with reference to the local geography, resulting in apparent mislocation with reference to the land-survey system.

Terms Describing Aquifer Characteristics

The capacity of an aquifer to store water is described by the porosity, the storage coefficient, and the specific yield of the aquifer. The capacity of an aquifer to transmit water is described by the hydraulic conductivity and the transmissivity of the aquifer.

Porosity (N) is the ratio of the volume of void space to the total volume of a rock or soil. Porosity is expressed as a decimal fraction or percentage.

The storage coefficient (S) of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in head. Storage coefficient is a dimensionless number.

Specific yield (Sy) is the ratio of (1) the volume of water which, after being saturated, a rock or soil will yield by gravity to (2) its own volume. Specific yield is expressed as a decimal fraction or percentage.

The hydraulic conductivity (K) of a water-bearing material is the volume of water that will move through a unit cross section of the material in unit time under a unit hydraulic gradient. The units for K are cubic feet per day per square foot, which reduces to feet per day.

Transmissivity (T) is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. The units for T are cubic feet per day per foot, which reduces to feet squared per day.

Acknowledgments

Individuals in several agencies have assisted in obtaining data for this study. These include individuals in the Bureau of Land Management offices in Hanksville and Monticello, Utah, and individuals in the National Park Service at the Halls Crossing and Bullfrog Marinas. Donald Ankrum, Rick Carr, Tab Hughes, Roy May, Beverly Morlang, and June Young of Plateau Resources, Inc. supplied data and assisted in obtaining data, and the officials of Plateau Resources allowed access to wells at the Ticaboo townsite, the Shootering Canyon Uranium Mill, and the Tony M. Mine.

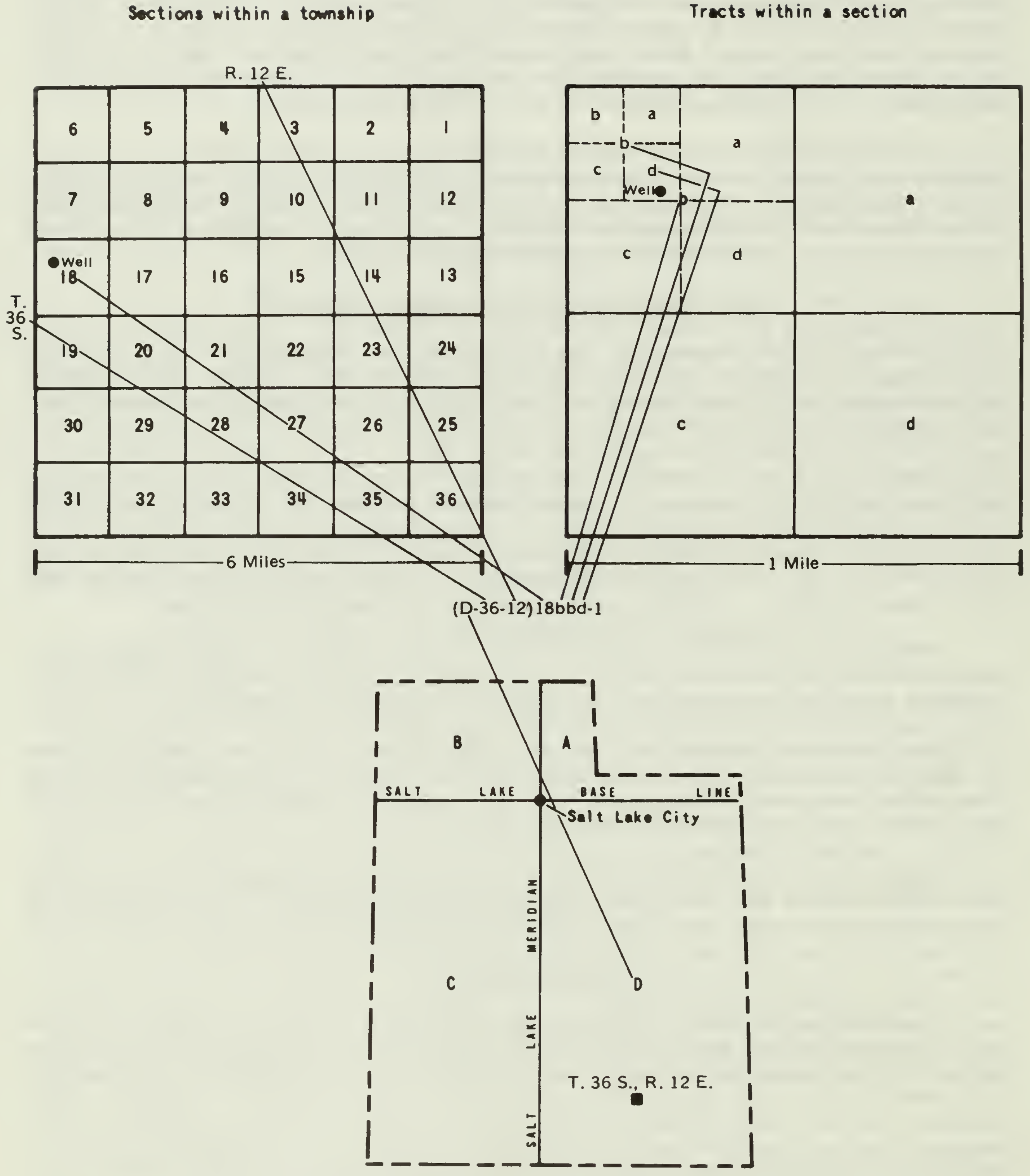


Figure 3.—Numbering system for hydrogeologic-data sites in Utah.

GEOLOGIC SETTING

The age of consolidated rocks exposed in the study area ranges from Permian to Tertiary (pl. 1). Location of outcrops and brief descriptions of the geologic and hydrologic characteristics of the geologic units exposed are described in table 1. Drillers' logs of selected wells (table 5, at back of report) give descriptions, thicknesses, and depths to the top of geologic units at selected sites.

The oldest rocks exposed in the study area are of Permian age. They include the Organ Rock Member and Cedar Mesa Sandstone Member of the Cutler Formation along the southeastern margin of the study area, and the Kaibab Limestone and Coconino Sandstone in small areas of Waterpocket Fold along the northwestern margin of the study area. Rocks as old as Cambrian age have been detected in the subsurface during oil-test drilling. Formations of the Mesaverde Group of Cretaceous age are the youngest consolidated sedimentary formations in the study area and are exposed in the extreme northwestern part of the study area.

The principal formations investigated in this report are, from oldest to youngest, the Lukachukai Member of the Wingate Sandstone of Triassic age, the Springdale Sandstone Member of the Moenave Formation and the Kayenta Formation of Triassic(?) age, the Navajo Sandstone of Triassic(?) and Jurassic age, and the Page Sandstone, the Carmel Formation, and the Entrada Sandstone, all of Jurassic age. The Wingate, Moenave, Kayenta, and Navajo form the Glen Canyon Group, and the Page, Carmel, and Entrada form part of the San Rafael Group. Of these formations, the Wingate Sandstone, the Navajo and Page Sandstones combined, and the Entrada Sandstone are the three principal aquifers.

The Lukachukai Member of the Wingate Sandstone is a reddish-brown, light-brown, or grayish-orange, very fine grained, moderately sorted, thickly crossbedded, aeolian sandstone. It erodes to vertical cliffs which are commonly coated with a dusky-red desert varnish. Thickness of the Lukachukai ranges from about 225 to 325 feet, and averages about 270 feet.

The Springdale Sandstone Member of the Moenave Formation is a pale-reddish-brown, medium-grained, micaceous, cliff-forming sandstone and minor shale. The Springdale Sandstone Member is present only in the southwestern part of the study area, thins from west to east, and wedges out in the vicinity of The Rincon and Nokai Dome. Maximum thickness of the Springdale Sandstone Member is about 100 feet.

The Kayenta Formation is a reddish-brown, reddish-orange, pale-gray, greenish-gray, and lavender fluvial sandstone, siltstone, and shale, with minor shale pellet conglomerate and freshwater limestone. The sandstone facies predominate, and the shale and siltstone facies are only lenses in the sandstone facies. The sandstone is fine-grained and moderately to very poorly sorted. The Kayenta interfingers with underlying and overlying formations, particularly with the overlying Navajo Sandstone. It erodes to cliffs and benches, and caps many mesas and narrow benches. Thickness of the Kayenta ranges from about 125 feet in the southern part of the study area to about 350 feet in the northern part, and averages about 270 feet.

Table 1.--Description of geologic formations in the Lake Powell area

[Geologic characteristics adapted from Stokes (1964), Hackman and Wyant (1973), and Peterson and Pipiringos (1979).]

Erathem	System	Series	Geologic unit	Principal locations of outcrop	Geologic characteristics	Hydrologic characteristics
Cenozoic	Quaternary		Relatively younger alluvial deposits, chiefly along active streams.	Small areas chiefly in tributary canyons north of Lake Powell; Lake Powell has covered the deposits in Glen Canyon.	Sand, silt, and gravel.	Probably would yield water to wells, but is unused.
			Gravel Surfaces	Chiefly in northeastern part of study area, near North Wash.	Mainly terraces and pediments undergoing erosion. May not be associated with active streams.	Good recharge medium.
			Landslide deposits	Extreme southeastern part of study area.	Deposits displaced chiefly by gravity.	Unknown.
			Dunes	Southwest of Mount Ellsworth overlying Entrada Sandstone; south of Moqui Canyon overlying Navajo Sandstone.	Chiefly quartz sand; includes both active and inactive accumulations.	Good recharge medium.
			Covering deposits	Chiefly east of Mount Ellen and near The Rincon.	Chiefly wind-blown silts lacking dune form. Some patches of soil and alluvium are included.	Unknown.
	Tertiary		Tertiary porphyritic intrusive rocks	Henry Mountains.	Intrusive igneous material forms cores of Henry Mountains and Navajo Mountain.	Perches water in overlying sedimentary rocks.
			Tertiary basic intrusive rocks	One small outcrop near mouth of Bullfrog Creek.	Basic intrusive material.	Unknown.
Mesozoic	Cretaceous	Upper	Mesaverde Group, undivided	Tarantula Mesa.	Mixed sandstone and shale. About 400 feet thick.	Do.
			Mancos shale:			
			Masuk Shale Member	Chiefly west of Mount Ellen and Mount Pennell.	Gray marine shale. 600 to 800 feet thick.	Probably does not yield water.
			Emery Sandstone Member	Chiefly west of Mount Ellen and Mount Pennell.	Light-colored marine sandstone, probably deltaic in origin. About 200 feet thick.	Yields small amounts (generally less than 2 gallons per minute) of poor quality water to springs and seeps.
			Blue Gate Shale Member	Large area chiefly west and southwest of Mount Ellen, Mount Pennell, and Mount Hillers; east of Waterpocket Fold.	Light gray calcareous marine shale. About 1,500 feet thick.	Probably does not yield water.
			Ferron Sandstone Member	On flanks of Mount Ellen, Mount Pennell, and Mount Hillers; southwest of Mount Hillers; east of Waterpocket Fold.	Marine and non-marine sandstone with numerous concretions and coal beds. 150 to 300 feet thick.	Unknown.
			Tununk Shale Member	On flanks of Mount Ellen, Mount Pennell, and Mount Hillers; southwest of Mount Hillers; east of Waterpocket Fold.	Gray marine siltstone and claystone. 525 to 650 feet thick.	Probably does not yield water. Forms confining bed above Dakota Sandstone.
			Dakota Sandstone	Large area west of Mount Holmes and Mount Ellsworth; small area east of Mount Pennell.	Light-colored sandstone and carbonaceous shale. Less than 50 feet thick.	Yields small amounts (generally less than 3 gallons per minute) of water to springs.
	Jurassic	Upper	Morrison Formation:	Navajo Mountain; east of Mount Ellen, Mount Pennell, and Mount Hillers; west of Mount Ellsworth and Mount Holmes.	Continental sediments. 500 to 600 feet thick.	
			Brushy Basin Member		Fluvial and lacusterine mudstone and sandstone.	Generally does not yield water. Forms confining bed between Dakota Sandstone and Salt Wash Sandstone Member.
			Salt Wash Sandstone Member		Uranium-bearing fluvial sandstone and mudstone.	Yields water in underground uranium mine in Shitamaring Canyon; yields small amounts (generally less than 2 gallons per minute) of water to springs.

Table 1.--Description of geologic formations in the Lake Powell area--Continued

Erathem	System	Series	Geologic unit		Principal locations of outcrop	Geologic characteristics	Hydrologic characteristics
Mesozoic	Jurassic	Middle	San Rafael Group	Summerville Formation	Small area of outcrop east of Mount Ellen and west of the Ticaboo townsite.	Chiefly thin-bedded siltstone, locally gypsiferous. 40 to 150 feet thick.	Probably does not yield water.
				Entrada Sandstone	Large outcrop areas east of Mount Ellen, Mount Pennell, and Mount Hillers; west of Mount Holmes; west, southwest, and southeast of Mount Ellsworth.	Smooth-weathering, non-marine siltstone and sandstone, cross-bedded in part. 500 to 800 feet thick.	Yields water to springs east of Mount Ellen, Mount Pennell, and Mount Hillers.
				Carmel Formation	Large outcrop areas along both sides of Glen Canyon; band of outcrop in eastern part of study area.	Marine gypsum, limestone, shale, and calcareous sandstone. 150 to 225 feet thick.	Yields small amounts (less than 1 gallon per minute) of water to springs and seeps east of the Ticaboo townsite. Generally forms a confining bed between Entrada and Navajo Sandstone.
		Lower	Glen Canyon Group	Navajo Sandstone (includes Page Sandstone above Navajo)	Large outcrop areas between the Colorado and San Juan Rivers, in the Navajo Mountain area, and in the northeastern part of the study area.	Cross-bedded, non-marine sandstone. 600 to 1,000 feet thick.	Yields several hundred gallons per minute of water to wells near the Ticaboo townsite and Bullfrog and Halls Crossing marinas, and smaller amounts to wells southeast of Halls Crossing. Yields water to springs throughout study area where formation crops out.
	- - ? - - -	- - ? - - -					
	Triassic (?)	Upper (?)		Kayenta Formation	Large outcrop areas in canyons and uplands along eastern and southeastern margins of study area; large outcrop area east of Navajo Mountain.	Chiefly fluvial cross-bedded sandstone with siltstone and shale lenses. 125 to 350 feet thick.	Yields water to springs in Glen Canyon and tributary canyons, but is considerably less permeable than overlying Navajo Sandstone or underlying Wingate Sandstone.
				Moenave Formation (Springdale Sandstone Member)	Present chiefly in Navajo Mountain area; crops out in canyon of the San Juan River and tributary canyons.	Cliff-forming sandstone and minor siltstone. Less than 100 feet thick.	Not known to yield water.
	Triassic	Upper		Wingate Sandstone (Lukachukai Member)	Large outcrop areas in canyons along eastern and southeastern margins of study area, and in uplands in part of the area between the Colorado and San Juan Rivers.	Cliff-forming, non-marine cross-bedded sandstone. 225 to 325 feet thick.	Yields small amounts (less than 5 gallons per minute) of water to wells in the Navajo Mountain area. Yields water to springs in canyons throughout study area where formation crops out.
			Chinle Formation		Outcrop areas along eastern and southeastern margins of study area, and west of Waterpocket Fold.	Varicolored beds of fluvial and lacustrine origin: generally sandy at top; limy, muddy, and bentonitic in the middle; sandy and conglomeratic (mainly Shinarump Member) near base. About 500 feet thick.	Sandy units yield small amounts (less than 1 gallon per minute) of water to springs in southeastern part of study area.
		Middle and Lower	Moenkopi Formation		Outcrop area along southeastern margin of study area, and west of Waterpocket Fold.	Chiefly mudstone and siltstone. 100 to 350 feet thick.	Not known to yield water.
Paleozoic	Permian		Kaibab Limestone		Minor outcrop west of Waterpocket Fold.	Light-gray, sandy limestone with much chert.	Do.
			Coconino Sandstone		Do.	Light-colored, cross-bedded, non-marine sandstone.	Do.
			Cutler Formation: Organ Rock Member		Minor outcrop area along southeastern margin of study area.	Thin-bedded sandstone and shale with minor limestone lenses.	Unknown.
			Cedar Mesa Sandstone Member		Do.	Cross-bedded, non-marine sandstone.	Do.

The Navajo Sandstone is a gray and yellowish-gray, locally reddish-orange, thickly crossbedded, fine- to very fine-grained, moderately to well sorted, aeolian sandstone containing a few thin lenses of dark-gray magnesian limestone partly altered to chert (fig. 4). The Navajo is slightly coarser grained near the top of the formation than near the base (table 2). The Navajo is characterized by large-scale, high-angle crossbedding in sets generally from 20 to 50 feet thick, and erodes to massive cliffs and domes. Thickness of the Navajo (including the Page Sandstone) ranges from slightly more than 600 feet in the northeastern part of the study area to more than 1,000 feet along Waterpocket Fold (fig. 5).

The Page Sandstone is a moderate reddish-brown, moderate reddish-orange, and locally very light gray or grayish-pink, fine-grained, well-sorted sandstone (Peterson and Pipiringos, 1979, p. 21). It is characterized by large-scale crossbedding, with sets generally ranging from 3 to 20 feet thick. Angular chert pebbles commonly occur at the base or in the basal 6 inches of the formation. The Page Sandstone is lithologically similar and hydrologically connected to the Navajo Sandstone, and is informally grouped with the Navajo in this report.

The Carmel Formation is composed of dusky-red limy siltstone, reddish-brown, fine-grained friable sandstone, and thin to thick beds of gypsum, all of marine origin. A siltstone bed about 10 feet thick is present at the top of the formation throughout most of the Henry Mountains area (fig. 6). The Carmel Formation erodes to ledgy slopes. Thickness of the Carmel ranges from about 150 to 225 feet, and averages about 175 feet.

The Entrada Sandstone is informally divided into three units. The upper and lower units are pale-gray to reddish-brown, fine-grained, moderately sorted aeolian sandstones. They are separated by a middle unit of alternating thick bed sets of pale to reddish-brown silty sandstone and dusky-red siltstone. The upper and lower units erode to cliffs and the middle unit erodes to slopes. Thickness of the entire formation ranges from about 500 to 800 feet thick.

Strata in the study area generally dip to the west at less than five degrees. In contrast to the general dip, strata dip steeply, locally as much as 30 degrees, to the east in the Waterpocket monocline. The dip of strata in anticlines and synclines generally is 10 degrees or less (pl. 1).

The cores of the Henry Mountains and Navajo Mountain are porphyrytic intrusive igneous rocks of Tertiary age. The intrusions have caused doming of the otherwise nearly flat-lying strata, and the dip of the sedimentary strata on the flanks of the mountains is in some places as much as 85 degrees. Nearly vertical strata on the southern flank of Mount Hillers is shown in figure 7. The three northern Henry Mountains (Mount Ellen, Mount Pennell, and Mount Hillers) have extensive exposures of igneous intrusive rock. Mount Holmes and Mount Ellsworth have small exposures of igneous rock. Only a small area of igneous rock, about one-eighth mile across, is exposed on the south side of Navajo Mountain and it does not appear on plate 1.

Figure 4.—Limestone lens (angular blocks) overlying crossbedded Navajo Sandstone (Jna) at (D-39-12)24d.

HYDROLOGIC SETTING

Precipitation

Annual precipitation ranges from less than 6 inches in the extreme southwestern part of the study area and along the San Juan River to more than 25 inches on the southern flank of Mount Ellen and on the summit of Mount Pennell (pl. 2). May through September precipitation ranges from less than 3 inches in the extreme southwest and along the San Juan River to more than 10 inches on Mounts Ellen, Pennell, and Hillers. Generally, less than 10 inches of precipitation falls annually and less than 6 inches falls from May through September on the plateaus. Total precipitation falling on the Lake Powell area is about 1,100,000 acre-feet annually and about 500,000 acre-feet from May through September. About 300,000 acre-feet of precipitation falls annually and about 120,000 acre-feet falls from May through September directly on the Navajo Sandstone.

Summer precipitation usually is in the form of thunderstorms, which are localized, intense, and short lived. There is little time for precipitation from such storms to infiltrate into the ground-water system, and most of the precipitation becomes runoff. Winter precipitation is less localized, less intense, and of longer duration; at higher altitudes it usually is in the form of snow. Winter conditions allow more time for precipitation to infiltrate into the ground-water system, especially at higher altitudes during spring melting of the winter snowpack.

Table 2.--Hydrologic and physical characteristics of shallow core and outcrop samples as determined by laboratory analysis

[Abbreviations used in headings are as follows: Kh, horizontal hydraulic conductivity; Kv, vertical hydraulic conductivity; ft/d, feet per day; mm, millimeters.]

Location: See "Numbering System for Hydrogeologic-Data Sites in Utah", p. 6, and figure 3.
Porosity: See p. 7.
Hydraulic conductivity (K): See p. 7. Air used for hydrologic analyses except where designated with W, distilled water.
Median grain size: d_{50}, 50th percentile.

Location	Porosity (percent)	Hydraulic Conductivity Horizontal Kh (ft/d)	Hydraulic Conductivity Vertical Kv (ft/d)	Ratio Kh/Kv	Median grain size (mm)
Navajo Sandstone near top of formation					
(D-32-12)14dab	24	4.51	4.52	1.00	0.177
(D-34-12)22bcd	20	4.81	1.83	2.63	.144
		4.18W			
(D-38-14)21bbd	23	13.52	8.61	1.57	.165
Navajo Sandstone near base of formation					
(D-32-13)19bdc	16	3.44	1.94	1.77	.105
		3.13W			
(D-38-13)36dda	24	3.49	2.18	1.60	.109
		2.86W			
(D-43-11) 4bba	13	2.73	3.81	.72	.154
		2.50W	3.58W	.70	
Navajo Sandstone near stratigraphic center of formation					
(D-40-12)10dca	13	1.44	1.54	.94	.134
		.76W			
Kayenta Formation					
(D-39-13) 1adc	20	.61	.05	12.2	.189
(D-43-11) 4bba	12	.06	.02	3.33	.125
		.006W	.0003W	20.0	

Table 2.--Hydrologic and physical characteristics of shallow core and outcrop samples as determined by laboratory analysis--Continued

Location	Porosity (percent)	Hydraulic Conductivity Horizontal Kh (ft/d)	Hydraulic Conductivity Vertical Kv (ft/d)	Ratio Kh/Kv	Median grain size (mm)
		Wingate Sandstone			
(D-32-13)33bbc	18	1.76	1.19	1.48	.109
(D-39-14) 9acd	5	5.75	.35	16.4	.105
(D-42-11)33dca	6	.67	.61	1.10	.144
		Entrada Sandstone			
(D-34-12) 3dda	14	.68	.85	.80	.177
(D-35-11)35cab	13	.13	.54	.24	.125

Surface-Water Conditions

Presently (1984), no surface-water gaging stations are operated in the Lake Powell area. Three partial-record stations and two water-stage recording stations were operated in the past (pl. 2). The two water-stage recording stations were station 09334000, North Wash near Hanksville; and station 09334500, White Canyon near Hanksville (U.S. Geological Survey, 1971). The period of record for both stations is May 1950 through September 1970. All of the drainage area upstream from station 09334000 is in the study area, and the average annual discharge during the 20-year period of record was 3,690 acre-feet. Only a small part of the drainage area upstream from station 09334500 is in the study area.

Cooley (U.S. Geological Survey, written commun., 1982) conducted a surface-water inventory of tributaries to the Colorado and San Juan Rivers in Glen Canyon and the canyon of the San Juan River. Tributaries, estimates of streamflow, and date of the estimates are listed in table 3. The majority of the streamflow estimates were made during either April or August and do not clearly represent base flow of the streams. In most cases, the April estimated values contain a component of spring runoff. The August estimated values are affected by evapotranspiration because of the hot summer temperatures and, in some cases, by summer thunderstorms. Because of these factors, a reliable determination of which streams are perennial could not be made. Streams that probably are perennial are Bullfrog Creek and Halls Creek near its mouth in the Henry Mountains area, streams in Moqui Canyon and Lake Canyon near the canyon mouths in the area between the Colorado and San Juan Rivers, and the streams in Cathedral Canyon and in Forbidding Canyon near its mouth in the Navajo Mountain area.

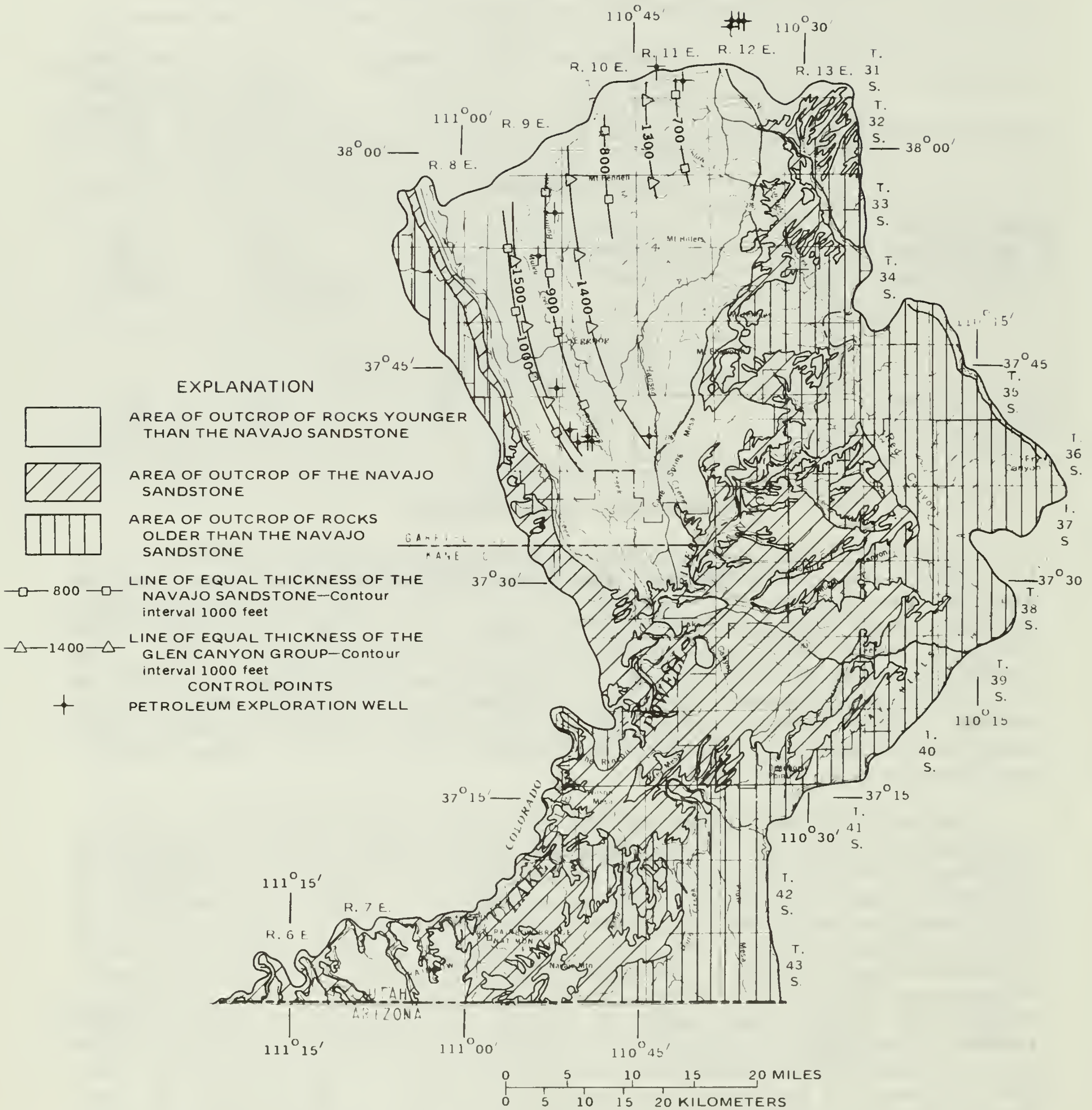


Figure 5.—Approximate thickness of the Navajo Sandstone and the Glen Canyon Group, undivided.

Figure 6.—Siltstone at top of the Carmel Formation at (D-34-12)10cba. Je, Entrada Sandstone; Jca, Carmel Formation.

Figure 7.– Nearly vertical strata on southern flank of Mount Hillers at (D-34-11)16a. Je, Entrada Sandstone; Jna, Navajo Sandstone.

Table 3.--Estimated discharge from tributaries to Glen Canyon and the canyon of the San Juan River

[Abbreviation: gal/min, gallons per minute]

Discharge from individual springs: --, no individual spring sites inventoried in tributary canyon.

Tributary	Gross discharge in stream channel		Discharge from individual springs		Net estimated discharge from seepage (gal/min)
	Date estimated	Discharge (gal/min)	Date estimated	Discharge (gal/min)	
		Henry Mountains Area			
Warm Spring Creek	8- 7-58	50	8- 7-58	85	0
	4-15-59	75			0
Smith Fork[1]	4-16-58	150	--	--	150
	8- 8-58	100			100
Hansen Creek	8- 8-58	100[2]	Various	25	75
	4-16-59	250			225
Halls Creek	8- 9-58	125	--	--	125
Total (gal/min)					300-500
(acre-feet)					484-806
		Area between the Colorado and San Juan Rivers			
Knowles Canyon	8- 7-58	Dry	4-15-59	5-10	0
	4-15-59	50			40-45
Forgotten Canyon	4-16-58	100	4-16-58	10-20	80-90
	8- 8-58	Dry			0
	4-15-59	40			20-30
Moqui Canyon	4-18-58	250-300	9-16-59	70	180-230
	4-22-59	800			730
Lake Canyon	4-20-58	900	Various	10	890
	8- 9-58	200			190
	4-16-59	800			790
Wilson Canyon	4-21-58	450	4-21-58	10	440
	8-10-58	15-20	8-10-58	10	5-10
	4-21-59	200			190
Wilson Creek	5-12-58	50	--	--	50
	6-24-58	50			50
Total (gal/min)					445-2,245
(acre-feet)					718-3,621

[1] Reported dry at times.
[2] Estimate obtained after summer rain.
[3] Tributary to Forbidding Canyon.
[4] 235 gallons per minute includes 130 gallons per minute from Bridge Canyon.

Table 3.--Estimated discharge from tributaries to Glen Canyon and the canyon of the San Juan River--Continued

Tributary	Gross discharge in stream channel		Discharge from individual springs		Net estimated discharge from seepage (gal/min)
	Date estimated	Discharge (gal/min)	Date estimated	Discharge (gal/min)	
		Navajo Mountain Area			
Rosebud Canyon	6-25-58	100	6-25-58	100	0
Nasja Creek and Bald Rock Canyon	6-25-58	40-50	Various	47-57	0
Bridge Canyon[3]	4-24-58	250	Various	120-135	115-130
	6-26-58	100			0
Aztec Creek[3]	4-24-58	10-15	11- -37	45	0
	6-26-58	1-2			0
Forbidding Canyon	4-24-58	1,000	Various	105-235[4]	765-895
	6-26-58	450			215-345
	4-21-59	1,000-1,200			765-1,095
Cathedral Canyon	8-13-58	150-200	--	--	150-200
Little Arch Canyon	8-13-58	5	--	--	5
False Entrance Canyon	8-14-58	5	9-17-59	5-10	0
Catfish Canyon	8-14-58	5-10	9-17-59	5-10	0-5
Grotto Canyon	8-14-58	5-10	8-14-58	5	0-5
	4-21-59	5			0
Dungeon Canyon	8-14-58	5	8-14-58	5	0
Total (gal/min)					370-1,440
(acre-feet)					597-2,323

Ground-Water Conditions

Information about occurrence and quality of ground water has been obtained from wells and springs throughout the Lake Powell area and is presented in tables 6 through 9 (at back of report). Both information obtained during this study and records of previous investigators (Davis and others, 1963; Kister and Hatchett, 1963; Iorns and others, 1964; Cooley, 1965; McGavock and others, 1966; Feltis, 1966; Goode and Olson, 1977) have been used in making the hydrologic evaluations presented in this report.

The Navajo Sandstone is the most utilized aquifer in the Lake Powell area, and the Entrada and Wingate Sandstones are also utilized for water supply. Most of the wells in the Henry Mountains area are completed in the Navajo. In the area between the Colorado and San Juan Rivers, wells are completed in the Navajo, the Wingate, or both. In the Navajo Mountain area, most of the wells are completed in the Wingate.

In both the Navajo Sandstone and the Wingate Sandstone, there is a prominent spring horizon at the base of the formations. These horizons are created by less permeable underlying formations that create perched ground-water bodies in the aquifers. The Kayenta Formation underlies the Navajo, and the Chinle Formation underlies the Wingate. A similar horizon is present at the base of the Entrada Sandstone. The Entrada is hydrologically significant only in the Henry Mountains area, and is underlain by the less permeable Carmel Formation. Many of the springs discharging from the Navajo and Wingate are located in Glen Canyon and in the canyon of the San Juan River at altitudes of less than 3,700 feet (Cooley, 1965), and are presently inundated by Lake Powell.

In the Henry Mountains area, ground water is present in the formations of the Glen Canyon Group, the Carmel Formation, the Entrada Sandstone, and in several formations younger than the Entrada Sandstone. Goode and Olson (1977) reported springs discharging from the Summerville and Morrison Formations, the Dakota Sandstone, several sandstone members of the Mancos Shale, and from fractured igneous rock. Sufficient water is in the Salt Wash member of the Morrison Formation that it requires dewatering at the Tony M. Mine near the Ticaboo townsite. Near the Ticaboo townsite and the Shootering Canyon uranium mill, the Navajo Sandstone is completely saturated; however, the altitude of the potentiometric surface decreases and the altitude of the base of the Navajo increases to the east, so that 4 miles southeast of the Ticaboo townsite, at well (D-36-12)18bbd-1, approximately the top 500 feet of the Navajo Sandstone are dry.

Both the Navajo Sandstone and the Entrada Sandstone have been used for water supply in the Henry Mountains area. Seven wells withdraw water from the Navajo Sandstone: Two wells are used for public supply at Bullfrog Marina, two wells are used to supply water for cooling operations at the Shootering Canyon Uranium Mill, one well supplies water to the Tony M. Mine, and one well supplies water for cooling operations and water for domestic use at the Ticaboo townsite. The seventh well is used for stock watering. Two wells that were previously used at the Tony M. Mine are completed in the Entrada Sandstone, and one well that supplies water to a business located about 2 miles south of the Ticaboo townsite is completed in both the Navajo and Entrada.

Generally, the Carmel Formation does not readily transmit water, and it is a confining unit that separates the ground-water system in the formations of the Glen Canyon Group from that in the Entrada Sandstone. The siltstone at the top of the Carmel Formation is the principal bed that limits ground-water movement between the two ground-water systems (fig. 6). Most of the remainder of the Carmel is sandy in the Henry Mountains area. West and northwest of Ticaboo Mesa, about 5 miles east of the Ticaboo townsite, the Carmel discharges water at several small seeps.

Between the Colorado and the San Juan Rivers,the youngest rock unit present generally is the Navajo Sandstone. There are only small areas where the Carmel Formation and Entrada Sandstone are present, and neither formation is hydrologically significant. The Navajo Sandstone, Kayenta Formation, and Wingate Sandstone all contain fresh water (less than 1,000 mg/L dissolved solids), and they generally act together as a single hydrologic unit, although the Kayenta has a considerably smaller hydraulic conductivity than either the

Navajo or Wingate. The spring horizon in Glen Canyon and in the canyon of the San Juan River near the base of the Navajo, now obscured by Lake Powell, demonstrates this smaller hydraulic conductivity. Rocks of the Glen Canyon Group yield fresh water to a public-supply well at Halls Crossing Marina and to five wells 10 to 15 miles southeast of Halls Crossing Marina. Two of the five wells are used for stock watering and three are presently (1984) unused.

In the Navajo Mountain area, the Navajo Sandstone generally is the youngest formation present to the east, north, and northwest of Navajo Mountain below an altitude of about 8,000 feet. Five wells have been drilled into bedrock 4 to 15 miles east of the summit of Navajo Mountain. In all five wells the Navajo Sandstone and Kayenta Formation are unsaturated, and generally only the bottom 5 to 40 feet of the Wingate Sandstone are saturated. Two drilled wells and one dug well are completed in alluvium in a valley near the Navajo Mountain Trading Post. These wells are the source of domestic water in the area, and the supply varies seasonally.

Water levels in three public-supply wells at Bullfrog and Halls Crossing Marinas have risen considerably since they were drilled--the water level in well T(D-38-11)29cda-1 at Halls Crossing Marina has risen about 220 feet since it was drilled in 1966. The wells are all located within 1 mile of Lake Powell, and the water levels have increased in response to the rising level of the reservoir as it filled Glen Canyon and increased bank storage in the canyon walls. Before the filling of the reservoir began in 1962, the level of the river in the vicinity of the wells was approximately 3,350 feet. The normal altitude of the surface of the lake is 3,700 feet, and this level was first achieved in 1980.

Hydrologic Characteristics of the Aquifers

Laboratory analyses for porosity, permeability, and grain size have been made on shallow core samples of the Navajo Sandstone, the Kayenta Formation, and the Entrada Sandstone, and on outcrop samples of the Wingate Sandstone. Seven samples from the Navajo, two from the Kayenta, three from the Wingate, and two from the Entrada were analyzed. Of the seven samples from the Navajo, three were from near the top of the formation, three were from near the bottom of the formation, and one was from near the stratigraphic middle of the formation. The results of the laboratory analyses are shown in table 2.

Except for those denoted with a "W", the hydraulic conductivity values reported in table 2 were calculated from air permeability values determined in the laboratory. Those values denoted with a "W" were calculated from distilled water permeability values. The values calculated using air as the fluid are somewhat larger than they would be if water were used as the fluid, and this condition is more severe for small hydraulic conductivities. For the Navajo Sandstone, where the hydraulic conductivity values determined from air permeabilities ranged from 1.44 to 13.52 feet per day, six hydraulic conductivity values determined from water permeabilities ranged from 53 to 94 percent of those determined from air permeabilities. For the Kayenta Formation, where the hydraulic conductivity values determined from air permeabilities ranged from 0.02 to 0.61 foot per day, two hydraulic conductivity values determined from water permeabilities ranged from 1.5 to 10 percent of those determined from air permeabilities.

The results of the laboratory analyses indicate that the hydraulic conductivity of the unfractured Navajo Sandstone generally is about 4 feet per day near the top of the formation and about 3 feet per day near the base of the formation. The hydraulic conductivity of the Wingate Sandstone generally is about 1 foot per day. The hydraulic conductivity of the Kayenta Formation appears to be considerably less than that of the Navajo or Wingate and probably adds little to the transmissivity of the Glen Canyon Group. The hydraulic conductivity of the Entrada Sandstone generally is less than 1 foot per day.

No aquifer tests were run successfully in the Lake Powell area during this study and, consequently, no transmissivity or storage coefficient values based on actual applied stress to the aquifers were determined. In the absence of such data, transmissivity values have been estimated using laboratory-determined hydraulic conductivity values and estimates of saturated thickness of the aquifers. Because the laboratory-determined hydraulic conductivity values generally were determined using air as the fluid, the estimated transmissivity values may be too large to the degree that the hydraulic conductivity using air is greater than that using water. Transmissivity also has been estimated from specific capacity determined at several well sites in the Henry Mountains area. The estimates were made using the graphs of Walton (1962, p. 12-13). The estimated transmissivities of the Navajo Sandstone, the Wingate Sandstone, and the Glen Canyon Group, undivided, are shown in table 4.

In the Henry Mountains area, the estimated transmissivity of the Glen Canyon Group varies greatly with location because of the large variation in saturated thickness of the Navajo Sandstone. At Bullfrog Marina the saturated thickness of the Navajo is about 1,000 feet, the estimated transmissivity of the Navajo is about 3,500 feet squared per day, and the estimated transmissivity of the entire Glen Canyon Group is about 3,750 feet squared per day (table 4). Near well (D-36-12)18bbd-1 the saturated thickness of the Navajo is about 250 feet, the estimated transmissivity of the Navajo is about 750 feet squared per day, and the estimated transmissivity of the entire Glen Canyon Group is about 1,000 feet squared per day (table 4).

Transmissivity of the Navajo Sandstone estimated from reported specific capacities at wells (D-36-11)16aba-2 and (D-36-11)16dbc-1 was, respectively, 750 and 900 feet squared per day, about one-third to one-fourth the transmissivity determined from hydraulic conductivity values. The specific capacities and the transmissivities estimated from those specific capacities are too small due to partial penetration of the aquifer by the wells. Using the equations and tables presented by Walton (1962, p. 7-8), the drawdown in the wells is about four times what it would be if the wells completely penetrated the Navajo section. Using a specific-capacity value of 1.8 feet per day instead of 0.45 foot per day and the graphs of Walton (1962, p. 12-13), the estimated transmissivity of the Navajo Sandstone is about 2,000 feet squared per day at well (D-36-11)16aba-2 and about 2,000 to 3,000 feet squared per day at well (D-36-11)16dbc-1.

Estimation of transmissivity of the Navajo Sandstone in the area between the Colorado and San Juan Rivers was hampered by the lack of stratigraphic data, which made the determination of the saturated thickness of the Navajo

Table 4.--Estimated transmissivity of the Navajo Sandstone, Wingate Sandstone, and Glen Canyon Group, undivided, at selected sites

[Estimated hydraulic conductivity values were determined by laboratory analysis of shallow core and outcrop samples; see Table 2. Abbreviations used in headings are as follows: ft, feet; ft/d, feet per day; ft^2/d, feet squared per day.]

Well number: See "Numbering System for Hydrogeologic-Data Sites in Utah", p. 6, and figure 3.

Well Number	Navajo Sandstone			Wingate Sandstone			Glen Canyon Group, undivided
	Estimated saturated thickness (ft)	Estimated hydraulic conductivity (ft/d)	Estimated transmissivity (ft^2/d)	Estimated saturated thickness (ft)	Estimated hydraulic conductivity (ft/d)	Estimated transmissivity (ft^2/d)	Estimated transmissivity (ft^2/d)
Henry Mountains Area							
(D-35-11) 2cba-1	750	3.5	2,625	250	1.0	250	2,875
(D-36-11) 3bbc-1	800	3.5	2,800	250	1.0	250	3,050
3bbd-1	800	3.5	2,800	250	1.0	250	3,050
16aba-1	800	3.5	2,800	250	1.0	250	3,050
16aba-2	800	3.5	2,800	250	1.0	250	3,050
16dbc-1	800	3.5	2,800	250	1.0	250	3,050
(D-36-12)18bbd-1	250	3.0	750	250	1.0	250	1,000
(D-38-11) 5dad-1	1,000	3.5	3,500	250	1.0	250	3,750
5dca-1	1,000	3.5	3,500	250	1.0	250	3,750
Area Between the Colorado and San Juan Rivers							
T(D-38-11)29cda-1	500	3.5	1,750	250	1.0	250	2,000
(D-38-12)35abc-1	200	3.0	600	300	1.0	300	900
(D-39-12)24dac-1	250	3.0	750	300	1.0	300	1,050
(D-39-13) 8bad-1	0		0	300	1.0	300	300
16aab-1	0		0	300	1.0	300	300
(D-40-12)11cca-1	50	3.0	150	300	1.0	300	450
Navajo Mountain Area							
(D-42-12)31aba-1	0		0	8	1.0	8	8
(D-43-10)28daa-1	0		0	40	1.0	40	40
34bab-1	0		0	4	1.0	4	4
(D-43-11) 6dcd-1	0		0	300	1.0	300	300
(D-43-12)17bbd-1	0		0	4	1.0	4	4
29baa-1	0		0	18	1.0	18	18

Sandstone difficult. Only one driller's log was available, from well T(D-38-11)29cda-1, and the altitude of the base of the Navajo could be determined in only a few locations in canyons in the area.

Thickness of the Navajo Sandstone was calculated by subtracting the altitude of the base of the Navajo, as determined in canyons where the contact between the Navajo and the Kayenta Formation is exposed, from the altitude of the top of the Navajo at the same location, as determined from figure 8. The altitude of the base of the Navajo was then extrapolated to areas where it could not be determined directly from outcrops by subtracting the approximate thickness of the Navajo (fig. 5) from the altitude of the surface of the Navajo (fig. 8). The approximate saturated thickness of the Navajo was then determined by subtracting the approximate altitude of the base of the Navajo from the altitude of water levels in wells in Townships 38, 39, and 40 South, Ranges 12 and 13 East. The estimated saturated thickness of the Navajo at the well sites ranged from 0 to about 250 feet, and the estimated transmissivity ranged from 0 to about 750 feet squared per day (table 4).

Water is present in the underlying Kayenta Formation and Wingate Sandstone, and these formations comprise the aquifer where the Navajo is dry. The thicknesses of the Kayenta and Wingate are not accurately known in this area, but drillers' logs of wells south of the San Juan River in the Navajo Mountain area (table 5) indicate that the Kayenta is about 150 feet thick and the Wingate is about 300 feet thick. Combination of the saturated thickness information and hydraulic conductivity values from table 2 produced a range of transmissivity values for the entire Glen Canyon Group from about 300 to about 2,000 feet squared per day (table 4).

Transmissivity of the Glen Canyon Group in the eastern part of the Navajo Mountain area generally is attributable only to the Wingate Sandstone--the Navajo Sandstone and the Kayenta Formation are dry in most places. Saturated thickness of the Wingate generally ranges from 4 to 40 feet, and the estimated transmissivity generally ranges from about 4 to about 40 feet squared per day (table 4). At well (D-43-11)6dcd-1, the saturated thickness of the Wingate was reported to be about 300 feet, and the estimated transmissivity based on saturated thickness and laboratory-determined hydraulic conductivity of the formation is 300 feet squared per day; however, the specific capacity of the well is only about 0.001 gallon per minute per foot of drawdown. Transmissivity of the Wingate at the well cannot be estimated from the graphs of Walton (1962) because the specific capacity is too small, but extrapolation of the graphs indicates that the transmissivity based on specific capacity of the well probably is less than 100 feet squared per day.

The hydraulic conductivity determined by laboratory analysis of shallow cores and outcrop samples is only a rough estimate of the in situ hydraulic conductivity. The results of laboratory analyses of cores and outcrop samples do not reflect the effects of fracturing, which can have a large effect on the ability of an aquifer to transmit water. Craft and Hawkins (1959, p. 283) report that a 0.001-inch wide fracture will have a permeability of 54,000 millidarcies, or a hydraulic conductivity of about 132 feet per day. This value is nearly two orders of magnitude larger than the hydraulic conductivity of unfractured Navajo Sandstone as determined from laboratory analyses (table 2), and open fractures even of this small size would greatly increase the hydraulic conductivity of the aquifers.

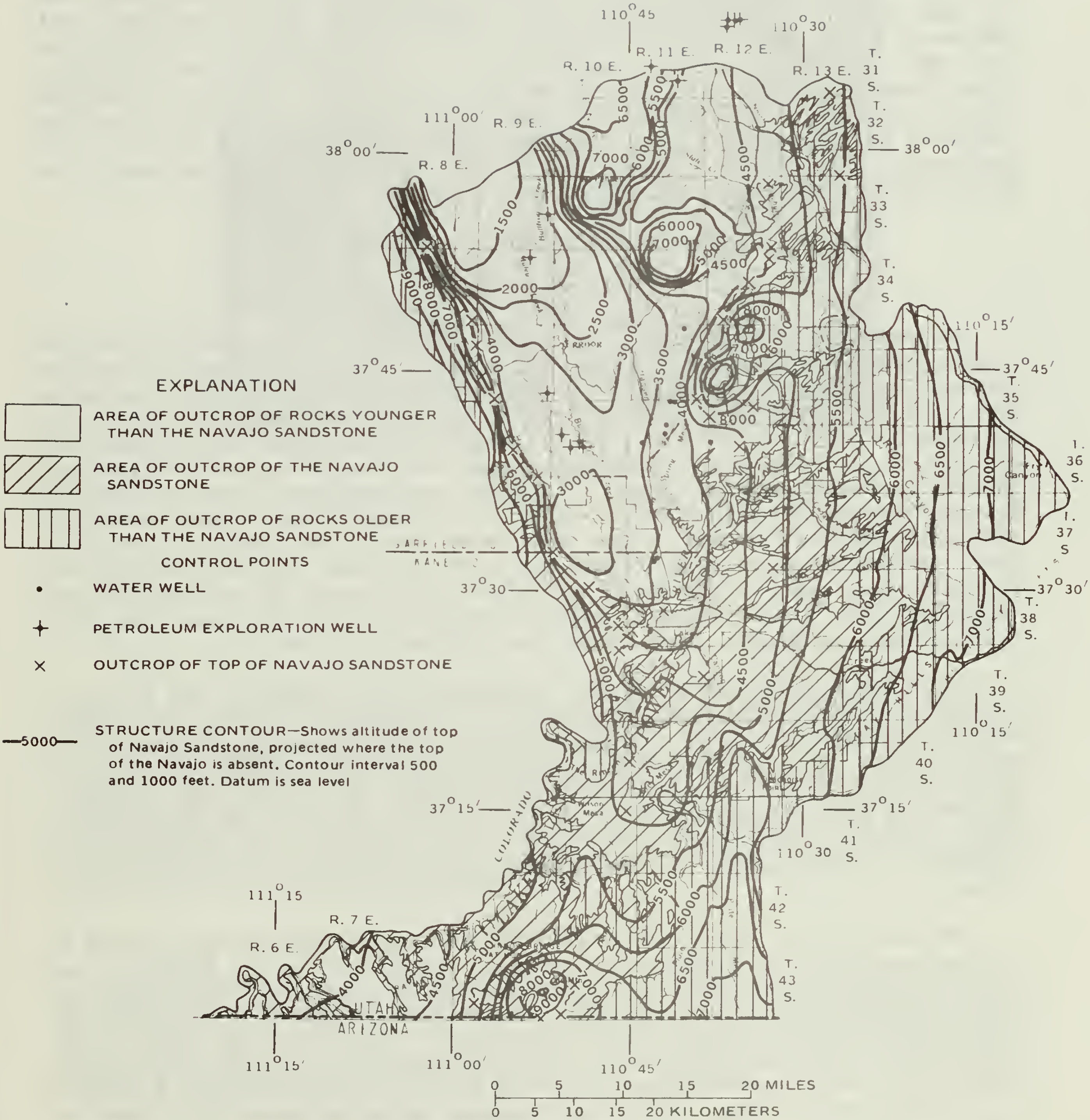


Figure 8.—Approximate altitude of the top of the Navajo Sandstone.

Fractures probably are common along the Waterpocket monocline, along the anticlines and synclines, and on the steeply dipping domal structures of the Henry Mountains and Navajo Mountain. In these areas, the in situ transmissivity may be much larger than that estimated from laboratory analysis if the fractures are either open or filled with material more permeable than the host rock. Conversely, the in situ transmissivity may be less than that estimated from laboratory analysis if the fractures in the aquifer are filled with material less permeable than the host rock. In several locations in the study area, material that has filled fractures in the Navajo or Entrada Sandstones has eroded at a slower rate than the Navajo or Entrada, and the fracture fill protrudes from the host rock. The fracture fill is more indurated and also may be considerably less permeable than the host rock. This condition in the Navajo Sandstone is shown in figure 9.

GROUND WATER IN THE AQUIFERS

Recharge

Recharge in the Lake Powell area is hard to estimate directly because records of precipitation and runoff are sparse, and also is hard to estimate indirectly from discharge because evapotranspiration is difficult to estimate. The amount of recharge to rocks of the Glen Canyon Group is small, and probably is about the same as the discharge from the group (see "Discharge" section). In the Henry Mountains area, the U.S. Bureau of Reclamation (Ronald L. Jensen, written commun., 1972) has estimated the potential recharge (the difference between precipitation and the sum of runoff plus potential evapotranspiration) for the entire area to be about 3,000 acre-feet per year. This recharge is to all the formations in the area and the Glen Canyon Group receives only part of the 3,000 acre-feet. The Bureau of Reclamation has estimated that little potential recharge occurs at altitudes less than 8,000 feet, where most of the rocks of the Glen Canyon Group crop out.

More recharge occurs at higher altitudes on the flanks of the mountains than on the plateaus and mesas adjoining the Colorado and San Juan Rivers. More precipitation falls on the mountains, and winter precipitation is in the form of snow. Slow melting of the snowpack in the spring allows time for the water to infiltrate into the ground-water system. On the plateaus and mesas, the average annual temperature is warmer and the amount of precipitation is less. Winter precipitation is either rain or snow. The rain runs off rapidly, and the smaller amount of snow melts and runs off soon after it falls.

Recharge to the Glen Canyon Group in the Henry Mountains area occurs by downward movement of water from overlying formations on the flanks of the mountains, where those formations are significantly fractured. The fracturing allows movement of water from the overlying Entrada Sandstone through the usually low-permeability Carmel Formation. Recharge also occurs from infiltration of precipitation falling directly on outcrops of rocks of the Glen Canyon Group, particularly where the rocks are significantly fractured, as along Waterpocket Fold. Additional recharge occurs by downward movement of water stored in overlying dune sand. Recharge to the Entrada Sandstone occurs similarly to recharge to the Glen Canyon Group, and additionally occurs by downward movement from large areas of overlying permeable dune sands southwest of Mt. Ellsworth.

Figure 9.—Fracture-fill material protruding from the Navajo Sandstone at (D-38-13)26bb. Arrow points to pencil used for scale.

In the area between the Colorado and San Juan Rivers, the Glen Canyon Group is recharged by direct infiltration of precipitation on the extensive outcrop areas, or by downward movement of water stored in overlying dune sand and locally sandy alluvium. In the Navajo Mountain area, the formations of the Glen Canyon Group are recharged on the flanks of Navajo Mountain, where the formations are upturned and significantly fractured. On the plateaus and mesas adjoining Navajo Mountain, additional recharge occurs from direct infiltration of precipitation on outcrop areas and from downward movement of water stored in overlying dune sand.

Movement

Precise direction of ground-water movement in the Glen Canyon Group could be determined for only a small part of the Lake Powell area because of the lack of water-level data; however, geologic structure and the location of discharge areas indicate that regional movement of ground water generally is toward the Colorado and San Juan Rivers. Direction of movement of water in the Glen Canyon Group is shown in figure 10.

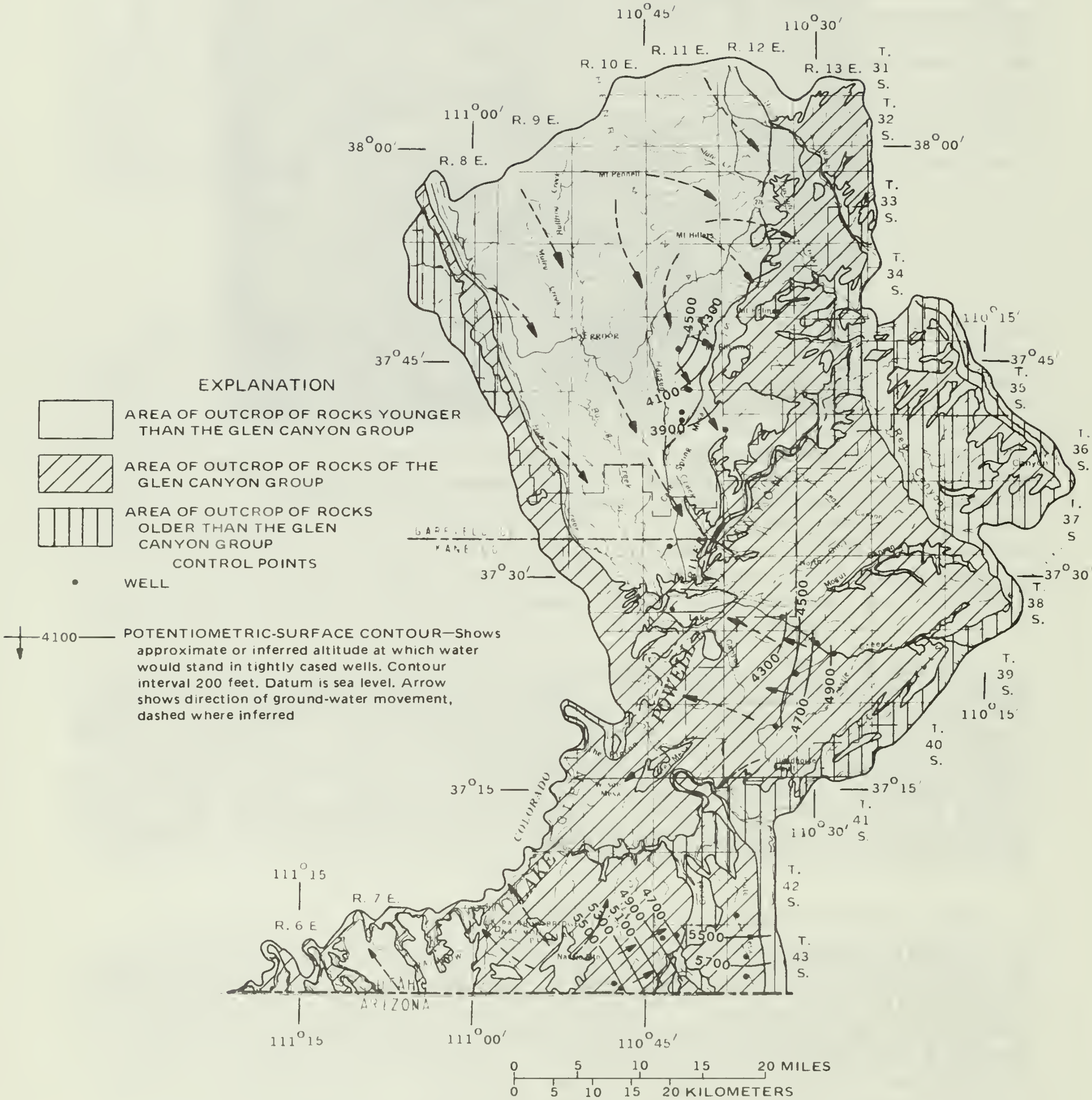


Figure 10.—Approximate potentiometric surface and general direction of movement of water in the Glen Canyon Group.

In the Henry Mountains area, the direction of ground-water movement in the Glen Canyon Group generally is to the southeast toward the Colorado River. Locally, there probably is radial ground-water movement from the peaks of the Henry Mountains. In the area between the Colorado and San Juan Rivers, the direction of ground-water movement generally is to the west toward the Colorado and San Juan Rivers, in the approximate direction of the regional dip. Locally, there probably is radial ground-water movement from Nokai Dome. In the Navajo Mountain area, the direction of ground-water movement generally is radial from Navajo Mountain. West of Navajo Mountain the direction of ground-water movement is northwest toward the Colorado River. East of Navajo Mountain the direction of ground-water movement is to the north toward the San Juan River, in the approximate direction of plunge of anticlines and synclines in the area.

Discharge

Discharge from rocks of the Glen Canyon Group generally is from small springs and seeps (with discharges of less than 10 gallons per minute) from canyon walls in Glen Canyon, the canyon of the San Juan River, and tributary canyons. The records of Davis and others (1963) and Cooley (1965) have been used extensively to determine the amount of discharge because inundation of the canyons by Lake Powell has precluded an inventory of spring sites at altitudes below 3,700 feet. Time limitations and inaccessibility have precluded a reinventory of many other sites. Annual discharge has been estimated by using measured or estimated spring discharges and assuming that those discharges are constant.

The effect that inundation by Lake Powell has on springs below 3,700 feet is unknown, but the ground-water system within a few miles of the lakeshore is not in equilibrium. The present (1984) discharge is less than when the system is in equilibrium, and water presently is being diverted into storage in the form of bank storage along the lakeshore. The water level in well (D-38-11)5dca-1, at Bullfrog Marina, is about 50 feet below the normal surface altitude of the reservoir, and the water level in well T(D-38-11)29cda-1, at Halls Crossing Marina, is about 150 feet below the normal surface altitude of the reservoir. Both water levels indicate that ground-water movement is from the reservoir into the canyon walls, and that a reversal of the normal ground-water gradient to Glen Canyon is present immediately along the shore of the lake. The reversal of the gradient probably will disappear and the amount of discharge probably will return to the approximate pre-Lake Powell amount when the ground-water system reachieves equilibrium, but that probably will not occur for about 500 years (Blakemore E. Thomas, U.S. Geological Survey, written commun., 1984).

Discharge in the Henry Mountains area occurs from the Entrada Sandstone, the Carmel Formation, and rocks of the Glen Canyon Group. Rocks younger than the Entrada Sandstone also discharge ground water (Goode and Olson, 1977), but that discharge is not considered here.

Discharge from the Entrada Sandstone occurs as seepage along stream channels that have only intermittent flow (fig. 11), and generally the seepage is from near the base of the formation. The seepage may be large enough to support some vegetation and form pools of water in the stream channel, but it normally is not large enough to provide flow in the stream channel. At some

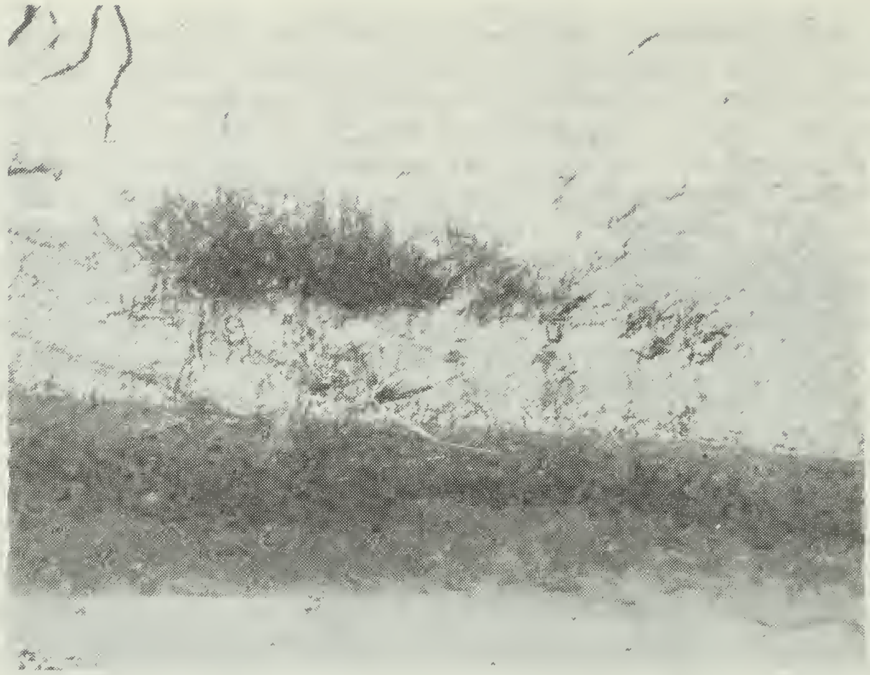


Figure 11.—Seepage (visible between vegetation and pool) from the Entrada Sandstone at (D-33-12)27bdd.

locations, box canyons contain large amounts of sand, and discharge may saturate enough of the sand to support large phreatophytes, such as cottonwood trees (populus sp.).

Discharge from the Carmel Formation is in the form of small seeps. Most of the known discharge occurs west and northwest of Ticaboo Mesa, about 5 to 6 miles east of the Ticaboo townsite. The discharge is large enough at only two locations to supply a holding tank or cattle trough.

Prior to the filling of Lake Powell, discharge from the Glen Canyon Group in the Henry Mountains area occurred principally from small springs and seeps in Glen Canyon and in tributary canyons 1 to 2 miles from their mouths. A notable exception is in the North Wash area, where springs discharge from the base of the Wingate Sandstone more than 10 miles upstream from Glen Canyon. Assuming constant discharge, discharge from specific spring sites in the Henry Mountains area was about 450 acre-feet per year. About 60 percent of that discharge was from sites at altitudes below 3,700 feet. An additional 500 to 800 acre-feet per year that was unaccounted for by specific springs discharged from tributary canyons (Maurice E. Cooley, U.S. Geological Survey, written commun., 1982). See table 3. The total annual discharge from the Glen Canyon Group in the Henry Mountains area under equilibrium conditions is estimated to be from about 950 to 1,250 acre-feet, or about 1,000 acre-feet, with about 95 percent of the discharge coming from the Navajo Sandstone.

Prior to the filling of Lake Powell, discharge from the Glen Canyon Group in the area between the Colorado and San Juan Rivers occurred principally from small springs and seeps in Glen Canyon, the canyon of the San Juan River, and

in tributary canyons 1 to 2 miles from their mouths. Assuming constant discharge, discharge from specific spring sites was about 450 to 500 acre-feet per year. About 50 percent of that discharge was from sites at altitudes below 3,700 feet. About 250 acre-feet per year discharged from springs in Glen Canyon or in canyons tributary to Glen Canyon. Discharge from springs in the canyon of the San Juan River and tributary canyons was about 75 acre-feet per year. Discharge from springs in Moqui Canyon was about 110 acre-feet per year. Only about 25 acre-feet per year discharged from upland areas. An additional 700 to 3,600 acre-feet per year that was unaccounted for by specific springs discharged from tributary canyons (Maurice E. Cooley, U.S. Geological Survey, written commun., 1982). See table 3. The smaller value probably is more accurate because the larger value is based on estimates made during mid-April 1958 and 1959 and the estimates probably contain a component of runoff from spring melting of snowpack at higher altitudes. The total annual discharge from the Glen Canyon Group in the area between the Colorado and San Juan Rivers under equilibrium conditions is estimated to be from about 1,150 to 4,100 acre-feet, or about 1,000 to 4,000 acre-feet. The smaller value probably is the more accurate value.

Prior to the filling of Lake Powell, discharge from formations of the Glen Canyon Group in the Navajo Mountain area was principally from small springs and seeps into canyons. About three-fourths of the springs in the area had discharges of less than 10 gallons per minute. Assuming constant discharge, discharge from specific spring sites was about 1,000 acre-feet per year. About 45 percent of that discharge was from sites at altitudes below 3,700 feet. An additional 600 to 2,300 acre-feet per year that was unaccounted for by specific springs discharged from tributary canyons (Maurice E. Cooley, U.S. Geological Survey, written commun., 1982). See table 3. The smaller value probably is more accurate because the larger value is based on measurements made during mid-April 1958 and 1959 and the estimates probably contain a component of runoff from spring melting of snowpack at higher altitudes. The total annual discharge from the Glen Canyon Group in the Navajo Mountain area under equilibrium conditions is estimated to be from about 1,600 to 3,300 acre-feet, or about 1,500 to 3,000 acre-feet. The smaller value probably is the more accurate value.

About one-fourth of the 42 springs inventoried by Davis and others (1963) and Cooley (1965) in the Navajo Mountain area had discharges of greater than 10 gallons per minute, and four springs had discharges of more than 100 gallons per minute. Glen Canyon and the canyon of the San Juan River form an arc from the northwest to the northeast around Navajo Mountain at a distance of less than 10 miles from the summit. The rocks of the Glen Canyon Group are most likely significantly fractured throughout the area as a result of disturbance during the emplacement of the intrusive rocks that form the core of Navajo Mountain, and ground water moves through fractures to the canyons. Farther away from Navajo Mountain, beyond the area of significant fracturing, the occurrence of discharge is more typical of the rest of the Lake Powell area, occurring as small springs and seeps from canyon walls and floors, usually at rates of less than 10 gallons per minute.

Storage

The results of laboratory analyses of shallow core and outcrop samples collected in the Lake Powell area indicate that the effective porosity of the Navajo is about 20 percent, that of the Kayenta Formation is about 16 percent, and that of the Wingate Sandstone is about 10 percent (table 2). For the Navajo, the specific yield has been estimated to be about 50 percent of the effective porosity, or about 10 percent (J. W. Hood, U.S. Geological Survey, oral commun., 1984). The ratios of specific yield to effective porosity for the Kayenta Formation and the Wingate Sandstone are unknown, but the smaller ratios of hydraulic conductivity to effective porosity (table 2) indicate that the specific yield-effective porosity ratios are probably less, too. Therefore, the specific yield-effective porosity ratios have been chosen arbitrarily to be 25 percent for the Kayenta and 40 percent for the Wingate, or one-half and four-fifths that of the Navajo. The estimated specific yield for both the Kayenta and the Wingate is then 4 percent.

Because of the limited number and poor distribution of data available to determine the saturated thickness of the formations of the Glen Canyon Group, no attempt has been made to estimate the total amount of water recoverable from storage in the study area. Instead, the amount of water recoverable from storage per square mile has been estimated where sufficient data are available.

The values stated for water recoverable from storage in the Glen Canyon Group are the amounts that could be recovered if the Glen Canyon Group could be completely drained. The actual amounts of water recoverable from storage in the Glen Canyon Group are less than the amounts stated because of physical limitations, including well spacing and well yields; and various economic, legal, and environmental constraints.

In the Henry Mountains area, the amount of water recoverable per square mile from the Navajo Sandstone varies greatly. At Bullfrog Marina, the saturated thickness of the Navajo is about 1,000 feet, and the Navajo contains about 64,000 acre-feet of recoverable water per square mile. The Kayenta Formation and Wingate Sandstone are both about 250 feet thick, and each contains about 6,000 acre-feet of recoverable water per square mile. The total amount of recoverable water for the entire Glen Canyon Group is estimated to be about 76,000 acre-feet per square mile. About 4 miles southeast of the Ticaboo townsite, near well (D-36-12)18bbd-1, the saturated thickness of the Navajo is about 250 feet, and the Navajo contains about 16,000 acre-feet of recoverable water per square mile. The amount of recoverable water from the entire Glen Canyon Group near this site is estimated to be about 28,000 acre-feet per square mile.

In the area between the Colorado and San Juan Rivers, the saturated thickness of the Navajo Sandstone at five wells ranges from 0 to 250 feet, and the Navajo contains from 0 to about 16,000 acre-feet of recoverable water per square mile. The saturated thickness of the Kayenta Formation ranges from 100 to 150 feet and the Kayenta contains from about 3,000 to about 4,000 acre-feet of recoverable water per square mile. The saturated thickness of the Wingate Sandstone is about 300 feet and the Wingate contains about 8,000 acre-feet of

recoverable water per square mile. The total amount of recoverable water in the entire Glen Canyon Group ranges from about 11,000 to about 28,000 acre-feet per square mile.

In the Navajo Mountain area, the Navajo Sandstone and the Kayenta Formation are unsaturated at several well sites east of Navajo Mountain, and the saturated thickness of the Wingate Sandstone generally ranges from about 4 to about 40 feet. The Wingate generally contains from about 100 to about 1,000 acre-feet of recoverable water per square mile.

Storage of water in rocks of the Glen Canyon group has increased significantly along Glen Canyon and the canyon of the San Juan River as a result of inundation of the canyons by Lake Powell. The increase is evidenced by the rise in water levels in wells at Bullfrog and Halls Crossing Marinas. At well (D-38-11)5dca-1, at Bullfrog Marina, the water level has risen about 52 feet since the water level in the well was first measured in 1964; and at well T(D-38-11)29cda-1, at Halls Crossing Marina, the water level has risen about 220 feet since the water level was first measured in 1966. Filling of the reservoir began in 1962. The two wells are within 1 mile from the present (1984) lakeshore.

Chemical Quality

Dissolved-solids concentrations were determined for 45 water samples collected at 37 sites. The water was fresh (less than 1,000 mg/L dissolved solids) at all of the sites (see table 8). The maximum concentration was 389 milligrams per liter at spring (D-33-13)4cbc-S1. The dissolved-solids concentration was larger than 300 milligrams per liter at only five other sites. For water collected from formations of the Glen Canyon Group, the area between the Colorado and San Juan Rivers had the smallest average dissolved-solids concentration, 158 milligrams per liter, and the Henry Mountains area had the largest average dissolved-solids concentration, 288 milligrams per liter. The Navajo Mountain area had an average dissolved-solids concentration of 216 milligrams per liter.

In this report, chemical classification of ground water is according to the system of Davis and DeWiest (1966, p. 119). In the system, only ions present in quantities greater than 20 percent of the total milliequivalents per liter of cations or anions are used to name the water type. An ion present in quantities greater than 60 percent of the total milliequivalents of cations or anions is used alone to name the cation or anion type. In mixed water types, ions present in quantities greater than 20 percent, but less than 60 percent, of the total milliequivalents of cations or anions present are listed in descending order of concentration. For example, for the sample collected from well (D-35-11)16dcd-1 on November 2, 1983 (table 8), 56 percent of the total cation milliequivalents was sodium and 23 percent was magnesium. Fifty-six percent of the total anion milliequivalents was bicarbonate and 39 percent was sulfate. This water sample is classified as sodium magnesium bicarbonate sulfate.

The chemical type of water varies from one subdivision of the study area to another. In the Henry Mountains area, the cation type in the Navajo Sandstone is mixed. Most often the cation type is magnesium calcium sodium or magnesium sodium calcium, and the anion type is bicarbonate. Exceptions occur

at wells (D-35-11)16cdd-1 and (D-36-11)32cac-1 where magnesium and calcium are present in quantities less than 20 percent of the total cation milliequivalents, and at well (D-35-11)16dcd-1 where calcium is present in less than 20 percent of the total cation milliequivalents. Sulfate is a significant anion only at the same three wells, and at spring (D-38-11)31bdd-S1 at the mouth of Halls Creek. At these four sites the anion type is bicarbonate sulfate or sulfate bicarbonate.

The difference in water chemistry at the three wells is attributable to the source of water. Well (D-35-11)16cdd-1 is completed in the Entrada Sandstone. Well (D-35-11)16dcd-1 is completed in the Navajo Sandstone, but the well may not be effectively sealed from the overlying Entrada Sandstone and may be receiving water from that formation as well. The chemistry of the water in well (D-35-11)16dcd-1 is more similar to that of well (D-35-11)16cdd-1 than to that of nearby wells completed in the Navajo. Well (D-36-11)32cac-1 is open to both the Navajo and Entrada, and also to the Carmel Formation.

Between the Colorado and San Juan Rivers, the water type most often is calcium magnesium bicarbonate. Exceptions are springs (D-36-13)21cdb-S1 at the Little Rincon, (D-37-12)16abb-S1 at the mouth of Knowles Canyon, and (D-39-11)9bab-S1 at the mouth of Lake Canyon, where calcium, magnesium, and sodium are all significant cations, and spring (D-40-10)12bbc-S1 at the mouth of Wilson Canyon, where sodium is the sole significant cation. In the Navajo Mountain area, the water type is either calcium magnesium bicarbonate or calcium bicarbonate.

Ground water from several sites was analyzed for trace-metal concentrations (table 9). Concentrations of arsenic, barium, and boron were all less than the maximum recommended concentrations for drinking water of 0.05, 1.0, and 20 milligrams per liter, and only at well (D-36-11)32cac-1 did the water have a concentration of selenium greater than the maximum recommended for drinking water of 0.01 milligram per liter (Davis and DeWiest, 1966, p. 121).

Ground water from several wells and springs that discharge from the Navajo Sandstone has been analyzed for radionuclides (table 9). Nine analyses were made for uranium, five in the Henry Mountains area and four in the area between the Colorado and San Juan Rivers. Concentrations ranged from 0.9 to 6.2 micrograms per liter in the Henry Mountains area and from less than 0.5 to 1.1 micrograms per liter in the area between the Colorado and San Juan Rivers. The concentration of uranium in water from well (D-35-11)16dcd-1 was a minimum of three times the concentration at any other site. Ground water in the Glen Canyon group from the Henry Mountains area and from the area between the Colorado and San Juan Rivers was analyzed for gross alpha and gross beta radiation, and water from the Henry Mountains area had larger average concentrations of both. Water with the largest concentrations was at well (D-36-11)3bbc-1, where concentrations were about five times those at any other location.

Larger concentrations of radionuclides are expected in ground water in the Henry Mountains area because of the presence of uranium-rich deposits in the Salt Wash Member of the Morrison Formation. The Salt Wash Member has been mined for uranium in the Henry Mountains area since the 1950's. The larger

concentrations of radionuclides in ground water may be the result of: (1) The presence of the Salt Wash Member in the area; (2) the mining and processing of the Salt Wash Member, both past and present; or (3) both factors. The Morrison Formation is not present in the area between the Colorado and San Juan Rivers.

In the Lake Powell study area, the filling of Lake Powell appears to have had little effect on ground-water chemistry along the shore of the lake. Southwest of the Lake Powell study area, along the shore of Wahweap Bay, the filling of Lake Powell has affected the major-ion chemistry of ground water, and also has apparently caused an increase in arsenic concentrations at several wells to levels in excess of the maximum concentration recommended for drinking water of 50 micrograms per liter (Blanchard, 1986, p. 48-50). Water from wells (D-38-11)5dad-1 and (D-38-11)5dca-1 at Bullfrog Marina show only small changes in concentrations of major ions and dissolved solids with time (table 8), and the concentration of arsenic has remained well below the maximum concentration recommended for drinking water (table 9).

In summary, ground water in the Glen Canyon Group was fresh wherever it was sampled in the Lake Powell area. In the Henry Mountains area, ground water generally was magnesium calcium sodium bicarbonate or magnesium sodium calcium bicarbonate. In the area between the Colorado and San Juan Rivers ground water generally was calcium magnesium bicarbonate, and in the Navajo Mountain area it was either calcium magnesium bicarbonate or calcium bicarbonate. The concentration of selenium in ground water was greater than the maximum concentration recommended for drinking water at only one site. Concentrations of all other trace metals considered were less than the maximum concentration recommended for drinking water at all sites. Concentrations of radionuclides were larger in the Henry Mountains area than in the area between the Colorado and San Juan Rivers. The larger concentrations in the Henry Mountains area probably are due to the presence of the uranium-rich Salt Wash Member of the Morrison Formation, to the mining and processing of the Salt Wash Member, or to both factors. Based on only two sampling sites, the filling of Lake Powell appears to have had only a small effect on the chemistry of ground water near the shore of the lake.

Effects of Large-Scale Withdrawal

The withdrawal of large amounts of water from the Navajo Sandstone or from the Glen Canyon Group over a long period will cause large declines in water levels both at the pumping site and in the area surrounding the pumping site. Because of the small amount of recharge to and discharge from the Navajo and the Glen Canyon Group, large withdrawals would remove water from storage rather than divert it from natural discharge. To estimate the extent of declines in water levels, the effects of a hypothetical withdrawal plan have been investigated. The selected hypothetical pumping site is in the Henry Mountains area near the Ticaboo townsite, which is the only location in the study area where the Navajo Sandstone is used for water supply and the entire thickness of the Navajo is known to be saturated.

The discharge rate of the withdrawal plan is 40,000 acre-feet per year (about 55 cubic feet per second), about the amount of water required for cooling a large thermoelectric powerplant. The aquifer has been assigned a transmissivity of 5,000 feet squared per day. Two storage coefficient values

have been used: 0.001 for when the aquifer is operating under artesian conditions, and 0.1 for when the aquifer is operating under water-table conditions. The storage coefficient selected for artesian conditions is that estimated for the Navajo Sandstone by Hood and Danielson (1979) for the Caineville area just to the north of the Lake Powell area. The storage coefficient for water-table conditions has been chosen to match the estimated specific yield of the Navajo. The transmissivity and storage coefficients are good approximations of the Navajo Sandstone in the Henry Mountains area near the Ticaboo townsite, where the Navajo is about 1,000 feet thick, is completely saturated, and has about 300 feet of artesian head. The predicted results of withdrawal are shown in figures 12 and 13.

Figures 12 and 13 are based on the assumptions that the Navajo Sandstone is homogenous, isotropic, infinite in areal extent, and constant in permeability and thickness, and that the withdrawal is from a single well. The Navajo does not satisfy these assumptions, and withdrawal of 40,000 acre-feet per year would be from a well field rather than a single well; nevertheless, the theoretical drawdown projections give an order of magnitude estimate of the effects of withdrawal on water levels.

At the hypothetical pumping site there is about 300 feet of artesian head in the Navajo Sandstone. For locations near the pumping site, drawdown would reach 300 feet and water-table conditions would be achieved rapidly after the start of withdrawal, and drawdowns predicted using the storage coefficient of 0.1 would be more accurate. For locations far away from the pumping site, water-table conditions would not be achieved for some time, and the drawdowns predicted using the storage coefficient of 0.001 would be more accurate. For intermediate distances from the pumping site, the drawdowns would be in between the predictions based on the two storage coefficients. For example, the drawdown would reach 300 feet and the aquifer would begin operating under water-table conditions 0.5 mile from the pumping site after about 30 days of withdrawal, and 1 mile from the pumping site after about 120 days of withdrawal. Conversely, it would take more than 30 years for water-table conditions to be achieved 10 miles from the pumping site. The relationship between time since withdrawal began and the distance from the pumping site for drawdown to reach 300 feet is shown in figure 14.

Using the water-table storage coefficient of 0.1, the Navajo Sandstone at the pumping site would be able to provide water for less than 10 years before the aquifer would become completely drained. At about 2 miles from the pumping site, the drawdown would be about 450 feet after 10 years of withdrawal if artesian conditions are assumed, and about 110 feet after 10 years of withdrawal if water-table conditions are assumed. If withdrawal could continue indefinitely without dewatering the aquifer at the pumping site and artesian conditions are assumed, the drawdown would be about 230 feet at about 19 miles from the pumping site after 50 years of withdrawal.

Withdrawals of the magnitude discussed could have one or more of several impacts on the ground-water system, depending on the location of the pumping site. Among the possible effects are: (1) Rapid draining of the aquifer in areas where the saturated thickness is small, (2) greater declines in the altitude of the potentiometric surface than those predicted by the withdrawal plan if impermeable boundaries are intercepted by the cone of depression, and (3) potential interception of water from Lake Powell if water-level declines

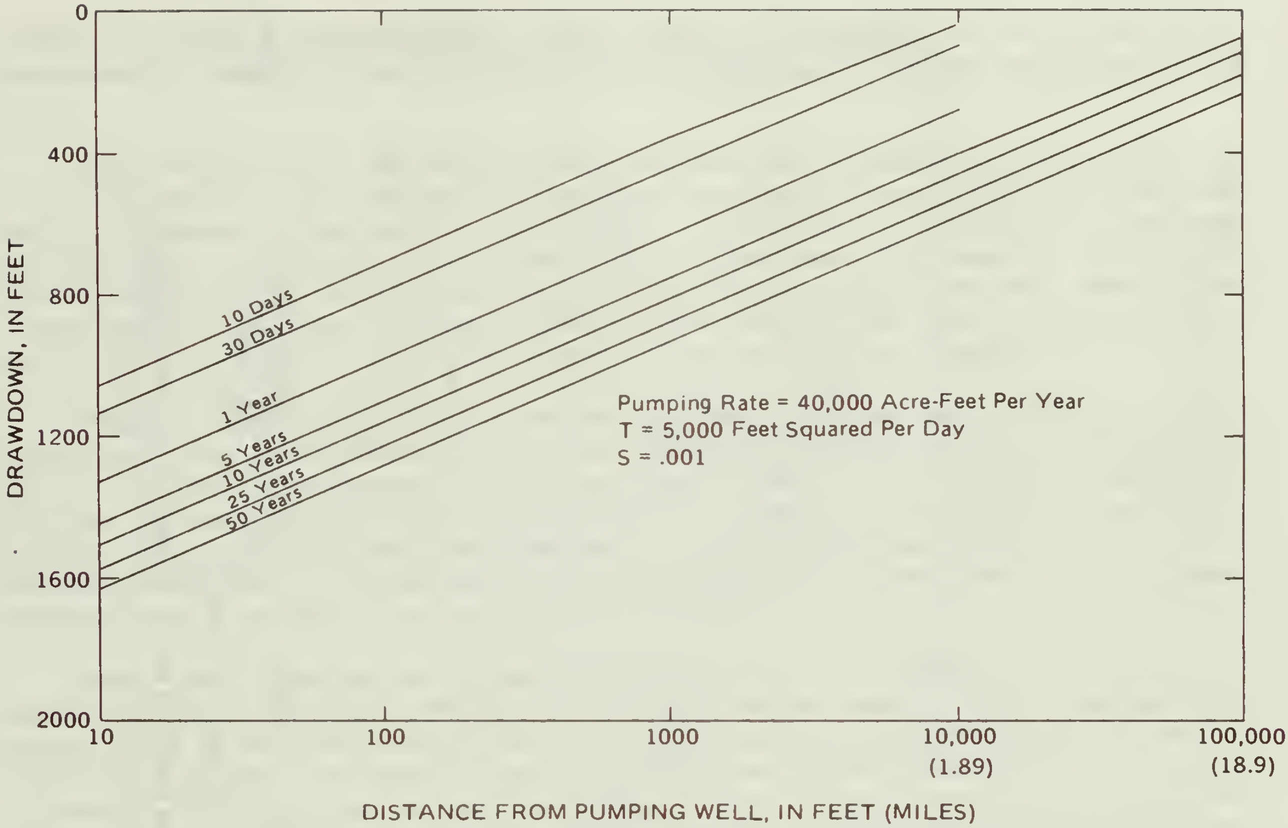


Figure 12.—Theoretical effect on water levels caused by withdrawals from the Navajo Sandstone operating under artesian conditions.

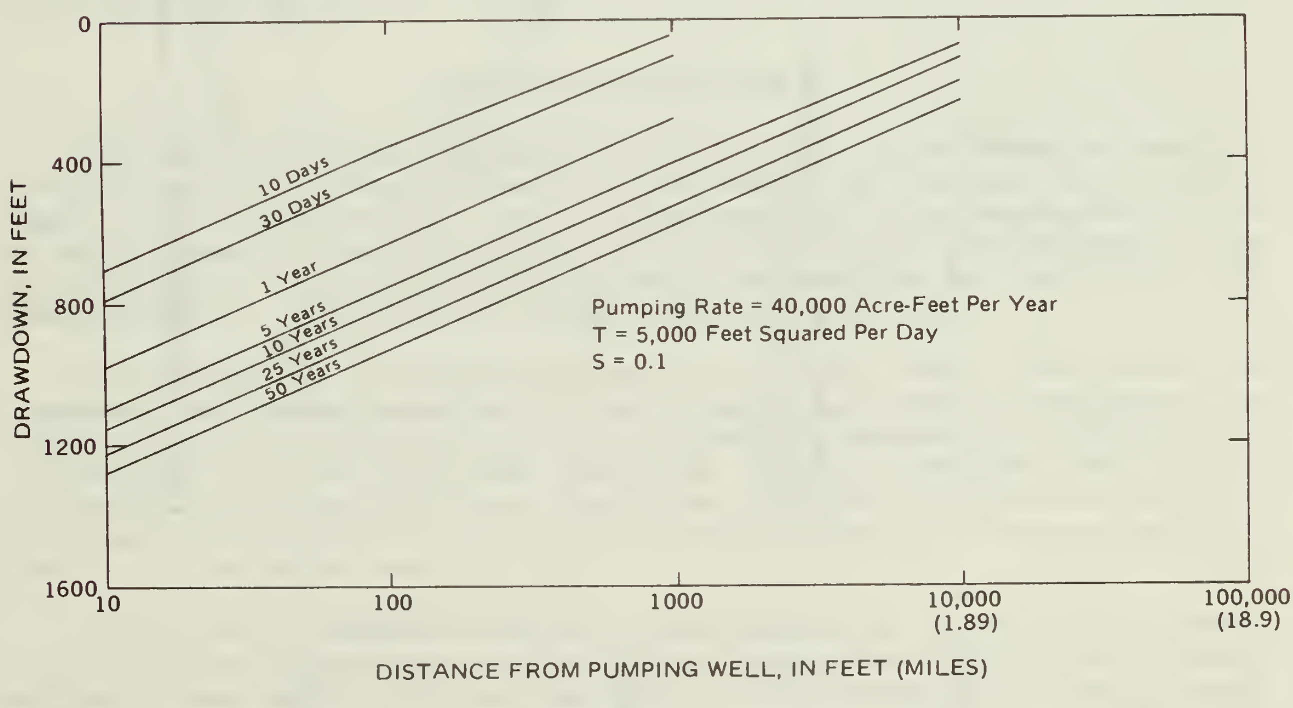


Figure 13.—Theoretical effect on water levels caused by withdrawals from the Navajo Sandstone operating under water-table conditions.

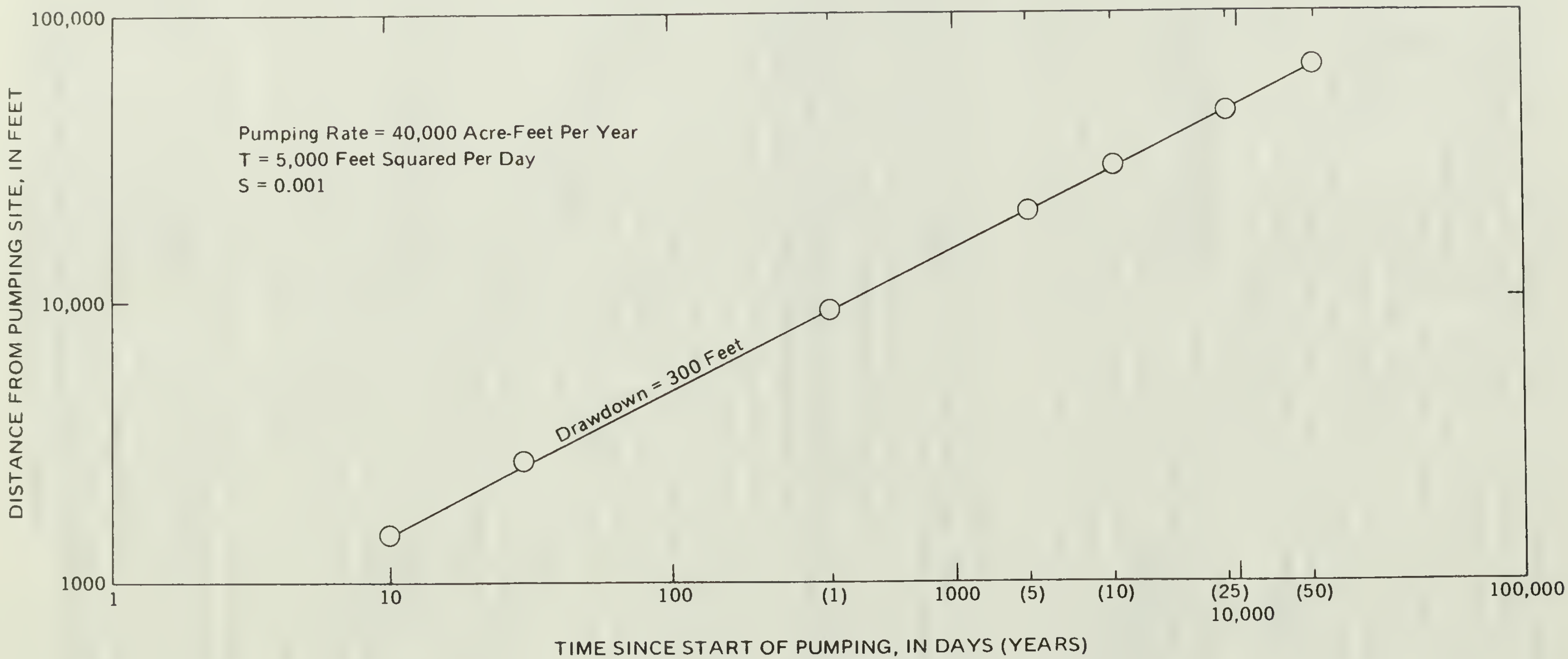


Figure 14.—Relationship of time versus distance from the pumping site to achieve 300 feet of drawdown.

resulting from withdrawal cause the altitude of the potentiometric surface to decrease to less than the normal surface altitude of Lake Powell of 3,700 feet.

Rapid draining of the aquifer from large-scale withdrawals of water would occur in parts of all three of the subdivisions of the study area. In the Henry Mountains area near well (D-36-12)18bbd-1, and in most of the area between the Colorado and San Juan Rivers, less than 300 feet of the Navajo Sandstone is saturated. Withdrawal of 40,000 acre-feet per year from these areas would drain the aquifer in only a few days (fig. 13). In most of the Navajo Mountain area the entire Navajo thickness is unsaturated.

Several impermeable boundaries are present in the Henry Mountains area. Among them are Waterpocket Fold to the west of the hypothetical pumping site, and each of the five peaks of the Henry Mountains to the north and northeast of the hypothetical pumping site. In the Waterpocket Fold, the Navajo Sandstone is upturned and unsaturated in the Waterpocket monocline, and in places is absent. The Navajo also is upturned on the domes of the Henry Mountains, and probably is unsaturated except on the lowest part of the domes.

Near the hypothetical pumping site, where the Navajo Sandstone is completely saturated and artesian, the altitude of water levels in wells is about 3,925 feet. Withdrawal of 40,000 acre-feet per year under artesian conditions in this area would lower the altitude of the potentiometric surface to about 3,700 feet, the normal surface altitude of Lake Powell, at a distance of about 1 mile from the pumping site in about 30 days. The altitude of the potentiometric surface in the Bullfrog and Halls Crossing Marina areas is presently (1984) below 3,700 feet. Withdrawal for public supply at the marinas presently causes potential interception of water from Lake Powell, and large-scale withdrawals would greatly increase the potential for diversion of water from Lake Powell.

SUMMARY AND CONCLUSIONS

The Lake Powell area comprises about 2,450 square miles in eastern Garfield County, extreme northeastern Kane County, and southwestern San Juan County of south-central Utah. It is subdivided into three geographical areas by the Colorado and San Juan Rivers. The Henry Mountains area is north of the Colorado River, the Navajo Mountain area is south of the San Juan River, and the third area is between the Colorado and San Juan Rivers.

The formations investigated during this study were, from oldest to youngest, the Wingate Sandstone of Triassic age, the Moenave Formation and the Kayenta Formation of Triassic (?) age, the Navajo Sandstone of Triassic (?) and Jurassic age, and the Page Sandstone, Carmel Formation, and Entrada Sandstone, all of Jurassic age. The Wingate, Moenave, Kayenta, and Navajo comprise the Glen Canyon Group, and the Page, Carmel, and Entrada comprise part of the San Rafael Group.

In the Henry Mountains area, water from the Entrada Sandstone, the Carmel Formation, and the Navajo Sandstone is used for water supply. The primary aquifer is the Navajo. In the area between the Colorado and San Juan Rivers and in the western part of the Navajo Mountain area, water is present in the

Navajo, the Kayenta, and the Wingate. In the eastern part of the Navajo Mountain area, the Navajo and Kayenta are dry, and generally only the bottom 4 to 40 feet of the Wingate are saturated.

Transmissivity of the Glen Canyon Group has been estimated from hydraulic conductivity values combined with estimates of saturated thickness of the formations, and from the specific capacities of wells. The hydraulic conductivity values were determined from laboratory analyses of shallow core and outcrop samples of the aquifers. In the Henry Mountains area, the estimated transmissivity ranges from about 1,000 to about 3,750 feet squared per day. In the area between the Colorado and San Juan Rivers, the estimated transmissivity ranges from about 300 to about 2,000 feet squared per day. In the eastern part of the Navajo Mountain area, the estimated transmissivity generally ranges from about 4 to about 40 feet squared per day.

The amount of recharge to the Glen Canyon Group is small, and probably is about equal to the amount of discharge. Small amounts of recharge to the Glen Canyon Group occur throughout the study area by direct infiltration of precipitation and by infiltration of water stored in dune sand where it overlies rocks of the Glen Canyon Group. In addition, the Glen Canyon Group is recharged by downward movement of water from overlying formations on the flanks of the Henry Mountains and Navajo Mountain, where those formations are domed and significantly fractured from emplacement of the igneous cores of the mountains.

Discharge from the Glen Canyon Group generally occurs via small springs and seeps discharging less than 10 gallons per minute. Most of the springs and seeps are in Glen Canyon, in the canyon of the San Juan River, or in tributary canyons 1 to 2 miles from their mouths. Annual discharge is about 1,000 acre-feet in the Henry Mountains area, about 1,000 acre-feet in the area between the Colorado and San Juan Rivers, and about 1,500 acre-feet in the Navajo Mountain area.

Water in rocks of the Glen Canyon Group was fresh wherever it was sampled throughout the Lake Powell area, having dissolved-solids concentrations of less than 1,000 milligrams per liter at all inventoried sites. In the Henry Mountains area, the water type is mixed, and the cation type generally is magnesium calcium sodium or magnesium sodium calcium. In the area between the Colorado and San Juan Rivers, the cation type generally is calcium magnesium. In the Navajo Mountain area, the cation type generally is calcium magnesium or calcium. Bicarbonate generally is the only significant anion throughout the study area.

Concentrations of radionuclides in ground water are larger in the Henry Mountains area than in the area between the Colorado and San Juan Rivers. The larger concentrations probably are due to the presence of the uranium-rich Salt Wash Member of the Morrison Formation, to the mining and processing of the Salt Wash Member, or to both factors.

To predict the effects of large-scale withdrawals of ground water from the Navajo Sandstone, the effects of a hypothetical withdrawal plan have been investigated. The hypothetical pumping site is near the Ticaboo townsite, where the Navajo is about 1,000 feet thick, completely saturated, and has about 300 feet of artesian head. The withdrawal of 40,000 acre-feet per year,

about the amount of water required for cooling a large thermoelectric powerplant, would completely drain the pumping site in less than 10 years. If withdrawal could continue indefinitely without dewatering the aquifer at the pumping site, the drawdown would be about 230 feet at a distance of about 19 miles from the pumping site after 50 years of withdrawal. Due to the small amount of recharge to and discharge from the Navajo Sandstone in the area, most of the water would come from storage rather than from diverted natural discharge.

Among the possible effects of large-scale withdrawals are: (1) Rapid draining of the aquifer in areas where the saturated thickness is small, (2) greater declines in the altitude of the potentiometric surface than those predicted by the withdrawal plan if impermeable boundaries are intercepted by the cone of depression, and (3) potential interception of water from Lake Powell if declines resulting from withdrawal cause the altitude of the potentiometric surface to decrease to less than the normal surface altitude of Lake Powell of 3,700 feet.

REFERENCES CITED

Brown, S. C., Halpenny, L. C., and Whitcomb, H. A., 1949, Water-supply investigation at Navajo Mountain, Navajo Indian Reservation, San Juan County, Utah: U.S. Geological Survey Open-File Report, 14 p.

Blanchard, P. J., 1986, Ground-water conditions in the Kaiparowits Plateau area, Utah and Arizona, with emphasis on the Navajo Sandstone: Utah Department of Natural Resources Technical Publication 81, 87 p.

Cooley, M. E., 1965, Stratigraphic sections and records of springs in the Glen Canyon region of Utah and Arizona: Museum of Northern Arizona Technical Series No. 6, 140 p.

Cooley, M. E., Harshbarger, J. W., Akers, J. P., and Hardt, W. F., 1969, Regional hydrology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 521-A, 61 p.

Craft, B. C., and Hawkins, M. F., 1959, Applied petroleum reservoir engineering: Englewood Cliffs, N.J., Prentice-Hall.

Davis, G. E., Hardt, W. F., Thompson, L. K., and Cooley, M. E., 1963, Geohydrologic data in the Navajo and Hopi Indian Reservation, Arizona, New Mexico, and Utah: Part I, records of ground-water supplies: Arizona State Land Department Water Resources Report 12-A, 159 p.

Davis, S. N., and DeWiest, R. J. M., 1966, Hydrogeology: New York, John Wiley, 463 p.

Feltis, R. D., 1966, Water from bedrock in the Colorado Plateau of Utah: Utah State Engineer Technical Publication 15, 82 p.

Fenneman, N. M., 1931, Physiography of the western United States: New York, McGraw-Hill, 534 p.

Goode, H. D., and Olson, Eric, 1977, Reconnaissance appraisal of the water resources of the Henry Mountains coal field, Wayne and Garfield Counties, Utah, 1975-1977: University of Utah, 43 p.

Gregory, H. E., 1916, The Navajo country: A geographic and hydrographic reconnaissance of parts of Arizona, New Mexico, and Utah: U.S. Geological Survey Water Supply Paper 380, 219 p.

_____1938, The San Juan country: A geographic and geologic reconnaissance of southeasten Utah: U.S. Geological Survey Professional Paper 188, 123 p.

Hackman, R. J., and Wyant, D. G., 1973, Geology, structure, and uranium deposits of the Escalante quadrangle, Utah and Arizona: U.S. Geological Survey Miscellaneous Investigations Map I-744, 2 sheets.

Hood, J. W., and Danielson, T. W., 1979, Aquifer tests of the Navajo Sandstone near Caineville, Wayne County, Utah: Utah Department of Natural Resources Technical Publication 66, 69 p.

_____1980, The Navajo Sandstone: a regional aquifer: Utah Geological Association 1980 Henry Mountains symposium, p. 267-276.

Hunt, C. B., Averitt, Paul, and Miller, R. L., 1953, Geology and geography of the Henry Mountains Region, Utah: U.S. Geological Survey Professional Paper 228, 234 p.

Iorns, W. V., Hembree, C. H., Phoenix, D. A., and Oakland, G. L., 1964, Water resources of the Upper Colorado River Basin - basic data: U.S. Geological Survey Professional Paper 442, 1,036 p.

Iorns, W. V., Hembree, C. H., and Oakland, G. L., 1965, Water resources of the Upper Colorado River Basin-technical report: U.S. Geological Survey Professional paper 441, 370 p.

Kister, L. R., and Hatchett, J. L., 1963, Geohydrologic data in the Navajo and Hopi Reservations, Arizona, New Mexico, and Utah, 1963: Part II, selected chemical analyses of the groundwater: Arizona State Land Department Water Resources Report 12-B, 58 p.

McGavock, E. H., Edmonds, R. J., Gillespie, E. L., and Halpenny, P. C., 1966, Geohydrologic data in the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: Part I-A, supplemental records of ground-water supplies: Arizona State Land Department Water Resources Report 12-E, 55 p.

Miser, H. D., 1924, The San Juan Canyon, southeastern Utah: a geographic and hydrographic reconnaissance: U.S. Geological Survey Water Supply Paper 538, 80 p.

Peterson, Fred, and Pipiringos, G. N., 1979, Stratigraphic relations of the Navajo Sandstone to Middle Jurassic Formations, southern Utah and northern Arizona: U.S. Geological Survey Professional Paper 1035-B, 43 p.

Stokes, W. L., [ed.], 1964, Geologic map of Utah: University of Utah, scale 1:250,000.

Strahler, A. N., 1970, Introduction to Physical Geography, second ed.: New York, John Wiley, 457 p.

Trewartha, G. T., 1968, An Introduction to Climate: New York, McGraw-Hill, 408 p.

U.S. Geological Survey, 1971, Index of surface-water records to September 30, 1970: U.S. Geological Survey Circular 659, 55 p.

U.S. Weather Bureau, (no date), Normal annual and May-September precipitation (1931-60) for the State of Utah: Map of Utah, scale 1:500,000.

Walton, W. C., 1962, Selected analytical methods for well and aquifer evaluation: Illinois State Water Survey Bulletin 49, 81 p.

Williams, P. L., and Hackman, R. J., 1971, Geology, structure, and uranium deposits of the Salina quadrangle, Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-591, 2 sheets.

Table 5.--Drillers' logs of selected water wells
[Geology partly interpeted by Paul J. Blanchard.]

Well numbers: See "Numbering System for Hydrogeologic-Data Sites in Utah", p. 6, and figure 3.
Altitude: Altitude of land surface at well, in feet.
Thickness: Thickness of unit, in feet.
Depth: Depth to base of unit, in feet below land surface.

Material	Thickness	Depth
(D-35-11)2cba-1. Log by Zimmerman Well Service. Altitude 5,080.		
Salt Wash Member of Morrison Formation	560	560
Entrada Sandstone	680	1,240
Carmel Formation	180	1,420
Navajo Sandstone		
Red sand	55	1,475
Red clay	25	1,500
Red sand	120	1,620
(D-36-11)3bbc-1. Log by Zimmerman Well Service. Altitude 4,480.		
Sand	6	6
Boulders	26	32
Entrada Sandstone	425	457
Carmel Formation		
Red clay and shale	193	650
Navajo Sandstone	350	1,000
(D-36-11)3bbd-1. Log by Zimmerman Well Service. Altitude 4,500.		
Sand	5	5
Boulders	15	20
Entrada Sandstone	425	445
Carmel Formation		
Red clay and shale	160	605
Navajo Sandstone	265	870
(D-36-11)16aba-1. Log by Unzicker and Wells Drilling Co., Inc. Altitude 4,360. Detailed sample log available in files of U.S. Geological Survey.		
Entrada Sandstone	490	490
Carmel Formation	280	770
Navajo Sandstone	152	922
(D-36-11)16aba-2. Log by Anzalone Pump and Drilling. Altitude 4,380.		
Sand	6	6
Entrada Sandstone	574	580
Carmel Formation	180	760
Navajo Sandstone		
Sandstone	225	985
Sandstone with lime	115	1,100
(D-36-11)16dbc-1. Log by Anzalone Pump and Drilling. Altitude 4,270.		
Sand	10	10
Sand, cobbles, and boulders	27	37
Entrada Sandstone	462	499
Carmel Formation	180	679
Navajo Sandstone		
Sandstone	156	835
Sandstone with gray shell	46	881
(D-36-11)32cac-1. Log by Unzicker and Wells Drilling Co., Inc. Altitude 3,920.		
Sand	10	10
Gravel and cobbles	20	30
Entrada Sandstone	150	180
Carmel Formation	200	380
Navajo Sandstone	60	440
(D-36-12)18bbd-1. Log by U.S. Geological Survey. Altitude 4,385.		
Top soil	10	10
Conglomeratic sandstone	30	40
Hardpan, red	10	50
Navajo Sandstone		
Sandstone, pink, easy to drill	260	310
Sandstone, red, easy to drill	420	730
Sandstone, brown, slightly harder	27	757
(D-38-11)5dad-1. Log by Jensen Const. and Drilling Co. Altitude 3,940.		
Sand	17	17
Entrada Sandstone	203	220
Carmel Formation		
Shale with chert and sandstone	160	380
Sandstone with shale and chert	70	450
Navajo Sandstone	555	1,005
(D-38-11)5dca-1. Log by Perry Brothers Drilling Co. Altitude 3,850.		
Sand	22	22
Entrada Sandstone	108	130
Carmel Formation		
Sandstone	40	170
Shale	30	200
Sandstone	100	300
Navajo Sandstone	413	713
T(D-38-11)29cda-1. Log by Stephenson Drilling. Altitude 3,910.		
Sand	5	5
Carmel Formation		
Red sandstone	10	15
Brown sandstone	65	80
Navajo Sandstone		
Red sandstone	974	1,054
(D-42-12)31aba-1. Log by Vivian Drilling Co. Altitude 5,830.		
Sand	22	22
Kayenta Formation	128	150
Wingate Sandstone	328	478
Chinle Formation	22	500
(D-43-10) 34bab-1. Log by Vivian Drilling Co. Altitude 6,040.		
Sand	2	2
Caliche	8	10
Kayenta Formation	260	270
Wingate Formation	225	495
Chinle Formation	25	520
(D-43-11)5ddb-1. Log by Vivian Drilling Co. Altitude 5,160.		
Sand	14	14
Navajo Sandstone	56	70
Kayenta Formation	164	234
Wingate Sandstone	286	520
Chinle Formation	35	555
(D-43-12)17bbd-1. Log by Vivian Drilling Co. Altitude 5,990.		
Kayenta Formation	30	30
Wingate Sandstone	314	344
Chinle Formation	36	380
(D-43-12)29baa-1. Log by Vivian Drilling Co. Altitude 6,200.		
Kayenta Formation	160	160
Wingate Formation	303	463
Chinle Formation	36	500

[Abbreviations used in headings are as follows: ft, feet; in, inches; gal/min, hr, hours; degrees C, degrees Celcius; μmhos/cm at 25° C,

Well number: See "Numbering System for Hydrogeologic-Data Sites in Utah", p. 6, and figure 3.
Principal aquifer: 110ALVM, alluvium of Quaternary age; 221ENRD, Entrada Sandstone; 220NVJO, Navajo Sandstone; 231WNGT, Wingate Sandstone;
Altitude: Altitude of land surface at well.
Finish: P, perforated; X, open hole without casing.
Water level (in feet below land surface): Column 1, method of measurement: L, geophysical log; R, reported; S, measured with steel tape. Column 2,
Other water quality data available: B, common ions; N, common ions, trace elements, and radionuclides; P, common ions and trace elements.

Well number	Owner	Principal aquifer	Date completed	Altitude (ft)	Depth of well (ft)	Depth to aquifer (ft)	Depth cased (ft)	Casing diam-eter (in)	Finish	Depth to first opening (ft)
(D-35-11) 2cba- 1	Plateau Resources	220NVJO	12- 1-79	5,080	1,620	1,420	1,596	6.88	X	1,596
16cdd- 1	Shitamaring Mine	221ENRD	11- -69	4,480	500	60	460	6	P	135
16dcd- 1	Shitamaring Mine	220NVJO	1975	4,490	1,000	--	--	--	-	--
16dcd- 2	Ekker, Harold	221ENRD	6-27-54	4,500	470	28	28	8	X	28
(D-36-11) 3bbc- 1	Plateau Resources	220NVJO	3- 7-78	4,480	1,000	650	603	6.63	X	603
3bbd- 1	Plateau Resources	220NVJO	1-20-78	4,500	870	605	636	6.63	X	636
16aba- 1	Ticaboo Development	220NVJO	11-11-77	4,360	922	770	--	5	-	--
16aba- 2	Ticaboo Development	220NVJO	3-26-79	4,380	970	760	800	10.75	X	800
16dbc- 1	Ticaboo Development	220NVJO	1-22-82	4,270	835	679	555	6	X	555
32cac- 1	Shipyard	(1)	4-28-81	3,920	440	380	40	6	X	40
(D-36-12)18bbd- 1	U.S. Bureau of Land Management	220NVJO	12-21-71	4,385	757	50	757	5	P	600
(D-38-11) 5dad- 1	U.S. National Park Service	220NVJO	1-27-70	3,940	1,005	450	1,005	10	P	550
5dca- 1	U.S. National Park Service	220NVJO	11- 4-64	3,850	713	300	713	10.75	P	613
(D-38-12)35abc- 1	U.S. Bureau of Land Management	220NVJO	1977	4,360	260	0	--	7	-	--
T(D-38-11)29cda- 1	U.S. National Park Service	220NVJO	12- 5-65	3,910	1,054	80	1,054	8	P	600
(D-39-12)24dac- 1	U.S. Bureau of Land Management	220NVJO	7- 1-76	4,790	540	0	--	6	-	--
(D-39-13) 8bad- 1	U.S. Bureau of Land Management	220NVJO	1900	4,840	275	0	--	6	-	--
16aab- 1	--	220NVJO	--	5,040	235	0	--	6	-	--
(D-40-12)11cca- 1	U.S. Bureau of Land Management	220NVJO	1950	4,820	400	0	--	7.50	-	--
(D-42-12)31aba- 1	Navajo Tribe	231LKCK	12- 8-63	5,830	500	150	42	5	X	42
(D-43-10) 7cac- 1	Navajo Tribe	231LKCK	1982	6,380	--	--	--	--	-	--
28daa- 1	Navajo Tribe	231LKCK	8- 1-46	6,020	823	284	--	8	-	--
28dad- 1	Navajo Mountain Trading Post	110ALVM	1935	6,000	20	--	20	108	-	--
34bab- 1	Navajo Tribe	231LKCK	12-18-63	6,040	520	270	20	5	X	20
(D-43-11) 5ddb- 1	Navajo Tribe	231LKCK	1-12-64	5,160	555	234	287	6	X	287
6dcd- 1	Navajo Tribe	231WNGT	6- -58	5,285	880	765	20	8	X	20
(D-43-12)17bbd- 1	Navajo Tribe	231LKCK	12-10-63	5,990	380	30	20	5	X	20
29baa- 1	Navajo Tribe	231LKCK	12-11-63	6,200	500	160	22	5	X	22

[1] Well is open to Entrada Sandstone, Carmel Formation, and Navajo Sandstone

selected water wells
gallons per minute; gal/min/ft, gallons per minute per foot of drawdown;
micromhos per centimeter at 25 degrees Celsius.]

231LKCK, Lukachukai Member of Wingate Sandstone.

site status: F, flowing; R, recently pumped.

Water level (ft)		Date water level measured	Discharge (gal/min)	Drawdown (ft)	Specific capacity (gal/min/ft)	Pumping period (hr)	Date discharge measured	Temperature (degrees C)	Specific conductance (μmhos/cm at 25°C)	pH (units)	Date quality parameters measured	Other water-quality data available
720	R	12- 1-79	60	400	0.2	72	12- 1-79	--	--	--	--	
120	R	1- 1-70	30	20	1.5	1	12- -69	20.0	610	8.4	8-30-76	P
140	R	8-30-76	75	--	--	--	8-30-76	21.0	400	8.5	8-30-76	N
--		--	20	--	--	--	7-25-54	--	--	--	--	
443	R	3-21-78	100	--	--	2	3-21-78	25.0	445	7.9	8- 1-83	N
445	R	3-22-78	120	15	8.0	7	2- -78	25.0	480	7.6	8- 1-83	N
438	L	11-14-77	100	--	--	--	11-12-77	--	--	--	--	
445.03	SR	4-14-83	130	270	0.5	21	3-26-79	22.0	435	7.7	8- 2-83	N
353.00	S	8- 1-83	70	163	0.4	12	8-18-82	--	--	--	--	
150	R	4-28-81	25	440	0.1	1	4-28-81	19.5	680	8.5	6-16-83	P
582	R	2-22-72	11	30	0.4	4	2-22-72	21.0	450	7.7	9- 9-83	N
568.47	S	9- 9-83										
357	R	3-21-70	150	122	1.2	24	3-29-70	22.0	300	8.1	4-14-83	P
250	R	12- 6-64	192	218	0.9	48	12-10-64	21.0	320	7.9	6-16-83	P
241.1	S	8- 6-68										
197.52	S	4-14-83										
133.27	S	9-10-83	7	--	--	--	9-10-83	18.0	105	8.5	9-11-83	N
580	R	1-18-66	20	10	2.0	--	1-30-66	21.0	150	8.4	10- 1-83	P
359.58	SR	10- 1-83										
238.49	SR	4-22-83	7	--	--	--	7- 1-76	16.5	210	8.2	4-24-83	P
89.64	S	4-24-83	--	--	--	--	--	--	--	--	--	
129.73	S	9-11-83	7	--	--	--	9-12-83	17.0	190	8.1	9-12-83	N
332.85	SR	10- 1-83	--	--	--	--	--	16.5	225	8.1	4-22-83	P
470	R	12-16-63	--	--	--	--	--	--	--	--	--	
	F	--	--	--	--	--	--	10.0	215	7.1	9-29-83	P
500	R	8- 1-46	0.2	--	--	--	8- 1-46	--	--	--	--	
13.3	R	7-10-48	--	--	--	--	--	13.5	535	--	7-10-48	B
491	R	12-19-63	--	--	--	--	--	--	--	--	--	
475	R	2-16-64	--	--	--	--	--	--	--	--	--	
533	R	6-24-58	0.5	34.5	<.1	--	6-24-58	--	--	--	--	
340	R	12-11-63	--	--	--	--	--	--	--	--	--	
445	R	12-12-63	--	--	--	--	--	--	--	--	--	

Table 7.--Records of

[Abbreviations used in headings are as follows: ft, feet; gal/min, gallons per minute; degrees

Spring number: See "Numbering system for Hydrogeologic-Data Sites in Utah", p. 6, and figure 3.
Principal aquifer: 110ALVM, alluvium of Quaternary age; 221CRML, Carmel Formation; 220GLNC, Glen Sandstone; 231LKCK, Lukachukai Member of Wingate Sandstone.
Altitude: Altitude of land surface at spring.
Discharge: E, estimated; R, reported; V, measured volumetrically (for example, with a bucket and
Other water quality data available: B, common ions; N, common ions, trace elements, and radionuclides;

Spring number	Name of spring	Owner	Principal aquifer	Altitude (ft)
(D-32-13)31dbc-S1	Hog Sp	--	220NVJO	4,440
(D-33-13) 4cbc-S1	South Hog Sp	U.S. Bureau of Land Management	231WNGT	4,090
15bdc-S1	North Wash Sp	--	231WNGT	3,900
T(D-35-12)27ccb-S1	Ticaboo Shelf Sp	U.S. Bureau of Land Management	221CRML	4,820
T(D-35-13)29bcc-S1	--	--	231LKCK	3,880
(D-36-12)32bdd-S1	--	--	220NVJO	3,575
32dad-S1	--	--	220NVJO	3,580
33ccc-S1	--	--	231WNGT	3,440
(D-36-13)21cdb-S1	--	--	231WNGT	3,790
(D-37-11)35bbb-S1	--	--	220NVJO	3,500
(D-37-12) 4bba-S1	--	--	220GLNC	3,440
16abb-S1	Knowles Canyon Sp	--	220NVJO	3,440
29bab-S1	--	--	220NVJO	3,600
(D-38-11)31bdd-S1	--	--	231WNGT	3,360
(D-38-13)23bcc-S1	--	--	231LKCK	4,700
29acd-S1	--	--	220GLNC	4,450
(D-39-11) 4dcc-S1	--	--	231KYNT	3,420
9bab-S1	--	--	220NVJO	3,360
20cac-S1	--	--	220NVJO	3,425
20cbc-S1	--	--	220NVJO	3,360
(D-39-14) 2bdc-S1	Irish Green Sp	--	231LKCK	5,430
10bca-S1	Green Water Sp	--	110ALVM	5,350
(D-40-10)12bbc-S1	--	--	231LKCK	3,300
(D-42- 9) 1acb-S1	--	Navajo Tribe	231LKCK	3,440
11abd-S1	--	Navajo Tribe	231LKCK	3,550
35bcb-S1	--	Navajo Tribe	220NVJO	4,500
(D-42-10)26aca-S1	--	Navajo Tribe	231LKCK	4,350
26bab-S1	Desha No. 1 Sp	Navajo Tribe	231LKCK	4,220
26bba-S1	--	Navajo Tribe	231LKCK	4,320
32bdc-S1	--	Navajo Tribe	220NVJO	4,950
(D-42-11) 9cca-S1	--	Navajo Tribe	231LKCK	3,900
(D-42-12)19aba-S1	--	Navajo Tribe	231KYNT	5,680
R(D-43- 8) 2dcd-S1	--	Navajo Tribe	220NVJO	3,550
12bcc-S1	Bridge Canyon Cr Sp	Navajo Tribe	220NVJO	3,600
35cda-S1	--	Navajo Tribe	220NVJO	4,050
(D-43- 9) 7aac-S1	--	Navajo Tribe	220NVJO	4,150
7bca-S1	--	Navajo Tribe	220NVJO	4,050
19baa-S1	--	Navajo Tribe	220NVJO	4,200

selected springs
C, degrees Celsius; μmhos/cm at 25° C, micromhos per centimeter at 25 degrees Celsius.]

Canyon Group; 220NVJO, Navajo Sandstone; 231KYNT, Kayenta Formation; 231WNGT, Wingate

stopwatch); W, measured with a weir.
P, common ions and trace elements.

Discharge (gal/min)	Date discharge measured	Temperature (degrees C)	Specific conductance (μmhos/cm at 25°C)	pH (units)	Date quality parameters measured	Other water quality data available
--	--	--	--	--	--	
5.0 E	7- 6-77	19.0	625	8.6	11- 1-83	B
--	--	14.5	560	7.5	6- 9-63	B
.3 E	8-18-75	24.0	440	--	8-18-75	P
20 E	7-22-58	--	--	--	--	
50 E	8- 7-58	--	--	--	--	
20 E	8- 7-58	--	--	--	--	
--	--	--	400	7.8	9- 9-57	B
5.0 E	4-23-59	--	295	8.0	4-23-59	B
20 E	9-16-59	--	--	--	--	
75 E	4-15-59	--	455	7.8	4-15-59	B
20 E	9- 9-57	--	500	7.6	9- 9-57	B
20 E	4-16-58	--	--	--	--	
180 E	10- 5-48	--	395	--	10- 5-48	B
20 E	9-16-59	--	--	--	--	
25 E	9-16-59	--	--	--	--	
3.0 E	8- 9-58	15.0	195	8.0	4-22-59	N
360 E	10- 4-48	--	410	--	10- 4-48	B
5.0 E	4-21-58	15.5	190	7.9	4-22-59	N
5.0 E	4-22-59	--	270	7.8	4-22-59	B
2.0 E	5-12-59	--	295	7.8	5-12-60	P
0.5 E	4-28-59	--	290	8.0	4-28-59	B
5.0 E	4-21-59	--	250	7.9	4-21-59	B
100 E	6-25-58	--	--	--	--	
45 E	6-25-58	--	--	--	--	
11 W	9-11-53	21.0	435	--	9-11-53	B
1.5 V	9- 2-53	13.0	320	--	9- 2-53	
3.5 V	9- 2-53	15.5	340	--	9- 2-53	
113 W	9- 2-53	15.5	375	--	9- 2-53	B
2.5 V	9-10-53	18.5	330	--	9-10-53	B
15 E	6-23-58	--	--	--	--	
<.1 E	7-29-54	17.0	240	--	7-29-54	B
30 E	6-26-58	--	--	--	--	
109 W	9-13-53	18.0	275	--	9-13-53	B
20 R	3- 3-53	--	--	--	--	
1.5 W	9-11-53	21.0	410	--	9-11-53	B
5.5 W	9-11-53	22.0	420	--	9-11-53	B
25 R	11- -37	--	--	--	--	

Table 8.--Selected chemical analyses of major

[Abbreviations used in headings are as follows: ° C, degrees Celsius; μmhos, "<" indicates that the actual value is unknown

Station Number: See "Numbering System for Hydrogeologic-Data Sites in Utah", p. 6, and figure 3.
Site: GW, well; SP, spring.
Geologic unit: 110ALVM, alluvium of Quaternary age; 221ENRD, Entrada Sandstone; 221CRML, Carmel Formation; 220GLNC, Glen Canyon Group; 231LKCK, Lukachukai Member of Wingate Sandstone.

Station number	Site	Geo-logic unit	Date of sample	Temper-ature (° C)	Spec-cific con-duct-ance (μmhos)	pH (units)	Alka-linity field (mg/L as $CaCO_3$)	Alka-linity lab (mg/L as $CaCO_3$)	Carbon Dioxide Dis-solved (mg/L as CO_2)	Hard-ness (mg/L as $CaCO_3$)	Calcium Dis-solved (mg/L as Ca)	Magne-sium Dis-solved (mg/L as Mg)
(D-33-13) 4cbc-S1	SP	231WNGT	10- 7-48	--	630	--	--	--	--	244	40	35
			4-27-59	18.0	530	7.5	--	--	--	300	53	41
15bdc-S1	SP	231WNGT	6- 9-63	14.5	560	7.5	--	--	--	210	34	31
(D-35-11)16cdd- 1	GW	221ENRD	8-30-76	20.0	610	8.4	--	--	--	100	21	12
16dcd- 1	GW	220NVJO	8-30-76	21.0	400	8.5	--	--	--	78	13	11
			11- 2-83	20.0	480	8.3	--	139	1.3	110	19	14
T(D-35-12)27ccb-S1	SP	221CRML	8-18-75	28.0	480	--	--	--	--	210	36	28
(D-36-11) 3bbc- 1	GW	220NVJO	8- 1-83	25.0	445	7.9	--	184	--	160	31	20
3bbd- 1	GW	220NVJO	8- 1-83	25.0	480	7.6	--	188	--	180	35	23
16aba- 2	GW	220NVJO	8- 2-83	22.0	435	7.7	--	182	--	160	30	20
32cac- 1	GW	(1)	6-16-83	19.5	680	8.5	--	153	--	28	5.4	3.5
(D-36-12)18bbd- 1	GW	220NVJO	9- 9-83	21.0	450	7.7	--	179	--	190	33	25
33ccc-S1	SP	231WNGT	9- 9-57	--	400	7.8	--	--	--	159	23	25
(D-36-13)21cdb-S1	SP	231WNGT	4-23-59	--	295	8.0	--	--	--	112	23	13
(D-37-12) 4bba-S1	SP	220GLNC	10- 4-48	18.5	470	--	--	--	--	206	38	27
			4-15-59	--	455	7.8	--	--	--	196	38	25
16abb-S1	SP	220NVJO	9- 9-57	--	500	7.6	--	--	--	234	46	29
(D-38-11) 5dad- 1	GW	220NVJO	2-27-74	--	305	6.5	119	--	73	112	17	17
			4-14-83	22.0	300	8.1	--	125	--	110	19	16
5dca- 1	GW	220NVJO	8- 8-68	22.0	310	7.7	128	--	5.0	120	21	17
			2-27-74	--	315	6.4	123	--	96	118	21	16
			6-16-83	21.0	320	7.9	--	127	--	120	20	18
31bdd-S1	SP	231WNGT	10- 5-48	--	395	--	--	--	--	182	50	14
(D-38-12)35abc- 1	GW	220NVJO	9-10-83	18.0	105	8.5	--	49	--	52	15	3.4
T(D-38-11)29cda- 1	GW	220NVJO	10- 1-83	21.0	150	8.4	--	75	--	71	16	7.4
(D-39-11) 4dcc-S1	SP	231KYNT	4-22-59	15.0	195	8.0	--	--	--	92	21	9.7
9bab-S1	SP	220NVJO	10- 4-48	--	410	--	--	--	--	160	36	17
20cac-S1	SP	220NVJO	4-22-59	15.5	190	7.9	--	--	--	92	21	9.7
20cbc-S1	SP	220NVJO	4-22-59	--	270	7.8	--	--	--	140	35	13
(D-39-12)24dac- 1	GW	220NVJO	4-24-83	16.5	210	8.2	--	96	--	100	26	8.7
(D-39-13)16aab- 1	GW	220NVJO	9-12-83	17.0	190	8.1	--	90	--	100	25	9.6
(D-39-14) 2bdc-S1	SP	231LKCK	5-12-60	--	295	7.8	--	--	--	127	28	14
			6-14-83	18.0	285	8.0	--	126	--	120	26	14
10bca-S1	SP	110ALVM	4-28-59	--	290	8.0	--	--	--	130	25	16
(D-40-10)12bbc-S1	SP	231LKCK	4-21-59	--	250	7.9	--	--	--	20	5.2	1.7
(D-40-12)11cca- 1	GW	220NVJO	4-23-83	16.5	225	8.1	--	108	--	110	24	13
(D-42- 9)35bcb-S1	SP	220NVJO	9-11-53	21.0	435	--	--	--	--	224	62	17
(D-42-10)26bba-S1	SP	231LKCK	9- 2-53	15.5	375	--	--	--	--	192	47	18
32bdc-S1	SP	220NVJO	9-10-53	18.5	330	--	--	--	--	300	84	22
(D-42-12)19aba-S1	SP	231KYNT	7-29-54	17.0	240	--	--	--	--	114	30	9.5
R(D-43- 8)12bcc-S1	SP	220NVJO	9-13-53	17.5	275	--	--	--	--	124	25	15
(D-43- 9) 7aac-S1	SP	220NVJO	9-11-53	21.0	410	--	--	--	--	196	42	22
7bca-S1	SP	220NVJO	9-11-53	22.0	420	--	--	--	--	202	43	23
(D-43-10) 7cac- 1	GW	231LKCK	9-29-83	10.0	215	7.1	--	102	--	110	28	8.6
28dad- 1	GW	110ALVM	7-10-48	13.5	535	--	--	--	--	276	66	27

[1] Well is open to Entrada Sandstone, Carmel Formation, and Navajo Sandstone.

constituents in ground water at selected sites
micromhos per centimeter at 25 degrees celsius; mg/L, milligrams per liter;
but is less than the indicated value.]

220NVJO, Navajo Sandstone; 231KYNT, Kayenta Formation; 231WNGT, Wingate Sandstone;

Sodium Dis-solved (mg/L as Na)	Potas-sium Dis-solved (mg/L as K)	Sodium + Potas-sium Dis-solved (mg/L as Na)	Bicar-bonate (mg/L as HCO_3)	Car-bonate (mg/L as CO_3)	Chlo-ride Dis-solved (mg/L as Cl)	Fluo-ride Dis-solved (mg/L as F)	Nitro-gen Nitrate Dis-solved (mg/L as NO_3)	Sulfate Dis-solved (mg/L as SO_4)	Silica Dis-solved (mg/L as SiO_2)	Solids Residue at 180°C Dis-solved (mg/L)	Solids Sum of Consti-tuents Dis-solved (mg/L)
--	--	50	301	--	9	--	0.3	91	15	--	389
--	--	3.4	349	--	5.5	0.2	.6	12	21	--	309
--	--	46	281	--	9.0	--	--	63	10	308	332
83	5.5	--	177	--	8.1	.3	--	130	15	368	369
55	4.6	--	153	--	8.0	.2	--	60	15	237	250
64	4.6	--	--	--	7.7	.3	--	94	16	302	304
20	2.9	--	197	--	24	.4	--	38	17	261	268
35	5.6	--	--	--	3.6	.2	--	59	15	257	280
35	5.9	--	--	--	4.1	.3	--	70	15	282	302
35	5.9	--	--	--	3.7	.2	--	53	14	256	272
130	3.6	--	--	--	13	.4	--	150	12	406	410
24	4.3	--	--	--	4.2	.2	--	61	11	255	271
--	--	34	192	--	6.0	--	1.4	63	16	--	262
--	--	23	162	0	7.8	.1	3.5	15	16	--	181
--	--	25	221	--	5	--	.7	68	13	--	286
--	--	30	234	--	5.5	.4	1.3	57	12	--	284
--	--	41	302	--	16	--	1.5	51	20	--	354
22	5.0	--	145	0	4	.1	.0	31	9	172	177
20	3.4	--	--	--	3.2	.2	--	33	11	163	181
20	3.7	--	156	0	2.7	.4	.7	35	11	170	189
22	3.0	--	150	0	4	.1	.0	34	10	180	184
21	3.8	--	--	--	3.1	.2	--	38	11	176	192
--	--	17	142	--	3	--	1.1	93	11	--	259
1.5	.8	--	--	--	1.5	<.1	--	5.3	11	67	68
5.2	2.1	--	--	--	2.4	<.1	--	4.4	9.8	86	93
3.4	1.4	--	106	0	2.0	.1	4.1	7.4	14	113	115
--	--	32	223	--	7	--	1.3	35	12	--	250
2.6	1.2	--	106	0	2.2	.1	3.4	6.2	18	109	116
--	--	4.3	174	0	3.0	.2	.4	1.6	11	--	155
3.7	1.1	--	--	--	3.3	<.1	--	6.8	12	123	119
2.0	1.1	--	--	--	3.5	<.1	--	6.9	12	115	114
14	1.2	--	157	0	10	--	1.5	11	14	--	171
13	1.4	--	--	--	11	.2	--	14	15	161	171
--	--	12	159	--	7.8	.2	3.2	12	17	--	171
--	--	56	157	0	3.5	.2	3.1	4.7	11	--	162
5.5	.9	--	--	--	3.9	<.1	--	9.4	16	124	138
--	--	6.4	257	0	8	.2	.9	15	29	--	264
--	--	6.9	220	0	9	.2	.9	12	17	--	219
--	--	6.9	366	0	6	.2	.8	5.4	24	--	329
--	--	6.4	128	0	5.0	.4	4.2	11	14	--	144
--	--	12	158	0	6	.2	1.9	10	12	--	160
--	--	13	234	0	9	.2	.8	18	14	--	234
--	--	13	232	0	11	.2	.4	22	17	--	244
4.5	1.5	--	--	--	3.8	.1	--	11	18	125	137
--	--	14	335	0	10	.0	.1	16	20	--	318

Table 9.--Selected chemical analyses of trace elements and radionuclides in ground water at selected sites

[Abbreviations used in headings are as follows: µg/L, micrograms per liter; pci/L, picocuries per liter; "<" indicates that the actual value is unknown but is less than the indicated value.]

Station Number: See "Numbering System for Hydrogeologic-Data Sites in Utah", p. 6, and figure 3.
Site: GW, well; SP, spring.
Geologic unit: 221ENRD, Entrada Sandstone; 221CRML, Carmel Formation; 220NVJO, Navajo Sandstone; 231KYNT, Kayenta Formation; 231LKCK, Lukachukai Member of Wingate Sandstone.

Station number	Site	Geo-logic unit	Date of sample	Arsenic Dis-solved (µg/L as As)	Barium Dis-solved (µg/L as Ba)	Boron Dis-solved (µg/L as B)	Sele-nium Dis-solved (µg/L as Se)	Gross Alpha Dis-solved (µg/L as U-NAT)	Gross Beta Dis-solved (pci/L as Cs-137)	Gross Beta Dis-solved (pci/L as Sr/Yt-90)	Radium 226 Dis-solved Radon method (pci/L)	Uranium, natural Dis-solved (µg/L as U)
(D-35-11)16cdd- 1	GW	221ENRD	8-30-76	3	--	70	--	--	--	--	--	--
16dcd- 1	GW	220NVJO	8-30-76	5	--	70	--	--	--	--	--	--
			11- 2-83	4	53	--	3	15	8.2	6.9	0.11	6.2
T(D-35-12)27ccb-S1	SP	221CRML	8-18-75	6	--	--	--	--	--	--	--	--
(D-36-11) 3bbc- 1	GW	220NVJO	8- 1-83	<1	66	--	1	51	39	33	.12	1.0
3bbd- 1	GW	220NVJO	8- 1-83	1	56	--	1	<10	6.8	5.7	.12	1.0
16aba- 2	GW	220NVJO	8- 2-83	<1	56	--	1	--	--	--	--	--
			11- 2-83	--	--	--	--	<11	6.2	5.2	.15	.9
32cac- 1	GW	([1])	6-16-83	22	33	--	13	--	--	--	--	--
(D-36-12)18bbd- 1	GW	220NVJO	9- 9-83	1	52	--	1	<11	5.1	4.2	.09	2.1
(D-38-11) 5dad- 1	GW	220NVJO	2-27-74	<1	<100	300	<1	--	--	--	--	--
			4-14-83	2	92	--	1	--	--	--	--	--
5dca- 1	GW	220NVJO	8- 8-68	10	--	70	0	--	--	--	--	--
			2-27-74	<1	<100	130	<1	--	--	--	--	--
			6-16-83	2	74	--	1	--	--	--	--	--
(D-38-12)35abc- 1	GW	220NVJO	9-10-83	2	22	--	<1	<2.1	<.8	<.7	.06	<.5
T(D-38-11)29cda- 1	GW	220NVJO	10- 1-83	2	330	--	1	--	--	--	--	--
(D-39-11) 4dcc-S1	SP	231KYNT	4-22-59	--	--	--	--	<1.1	--	--	.2	1.1
20cac-S1	SP	220NVJO	4-22-59	--	--	--	--	<.7	--	--	.1	.4
(D-39-12)24dac- 1	GW	220NVJO	4-24-83	2	36	--	1	--	--	--	--	--
(D-39-13)16aab- 1	GW	220NVJO	9-12-83	1	28	--	<1	<4.3	2.2	1.8	.04	.5
(D-39-14) 2bdc-S1	SP	231LKCK	6-14-83	5	170	--	2	--	--	--	--	--
(D-40-12)11cca- 1	GW	220NVJO	4-23-83	2	73	--	1	--	--	--	--	--
(D-43-10) 7cac- 1	GW	231LKCK	9-29-83	8	190	--	1	--	--	--	--	--

[1] Well is open to Entrada Sandstone, Carmel Formation, and Navajo Sandstone.

PUBLICATIONS OF THE UTAH DEPARTMENT OF NATURAL RESOURCES,
DIVISION OF WATER RIGHTS

(*)-Out of Print

TECHNICAL PUBLICATIONS

*No. 1. Underground leakage from artesian wells in the Flowell area, near Fillmore, Utah, by Penn Livingston and G. B. Maxey, U.S. Geological Survey, 1944.

No. 2. The Ogden Valley artesian reservoir, Weber County, Utah, by H. E. Thomas, U.S. Geological Survey, 1945.

*No. 3. Ground water in Pavant Valley, Millard County, Utah, by P. E. Dennis, G. B. Maxey and H. E. Thomas, U.S. Geological Survey, 1946.

*No. 4. Ground water in Tooele Valley. Tooele County, Utah, by H. E. Thomas, U.S. Geological Survey, in Utah State Engineer 25th Biennial Report, p. 91-238, pls. 1-6, 1946.

*No. 5. Ground water in the East Shore area, Utah: Part I, Bountiful District, Davis County, Utah, by H. E. Thomas and W. B. Nelson, U.S. Geological Survey, in Utah State Engineer 26th Biennial Report, p. 53-206, pls. 1-2, 1948.

*No. 6. Ground water in the Escalante Valley, Beaver, Iron, and Washington Counties, Utah, by P. F. Fix, W. B. Nelson, B. E. Lofgren, and R. G. Butler, U.S. Geological Survey, in Utah State Engineer 27th Biennial Report, p. 107-210, pls. 1-10, 1950.

No. 7. Status of development of selected ground-water basins in Utah, by H. E. Thomas, W. B. Nelson, B. E. Lofgren, and R. G. Butler, U.S. Geological Survey, 1952.

*No. 8. Conspumptive use of water and irrigation requirements of crops in Utah, by C. O. Roskelly and W. D. Criddle, Utah State Engineer's Office, 1952.

No. 8. (Revised) Consumptive use and water requirements for Utah, by W. D. Criddle, Karl Harris, and L. S. Willardson, Utah State Engineer's Office, 1962.

No. 9. Progress report on selected ground water basins in Utah, by H. A. Waite, W. B. Nelson, and others, U.S. Geological Survey, 1954.

*No. 10. A compilation of chemical quality data for ground and surface waters in Utah, by J. G. Connor, C. G. Mitchell, and others, U.S. Geological Survey, 1958.

*No. 11. Ground water in northern Utah Valley, Utah: A progress report for the period 1948-63, by R. M. Cordova and Seymour Subitzky, U.S. Geological Survey, 1965.

*No. 12. Reevaluation of the ground-water resources of Tooele Valley, Utah, by J.S. Gates, U.S. Geological Survey, 1965.

*No. 13. Ground-water resources of selected basins in southwestern Utah, by G. W. Sandberg, U. S. Geological Survey, 1966.

*No. 14. Water-resources appraisal of the Snake Valley area, Utah and Nevada, by J. W. Hood and F. E. Rush, U.S. Geological Survey, 1966.

*No. 15. Water from bedrock in the Colorado Plateau of Utah, by R. D. Feltis, U.S. Geological Survey, 1966.

*No. 16. Ground-water conditions in Cedar Valley, Utah County, Utah, by R. D. Feltis, U.S. Geological Survey, 1967.

*No. 17. Ground-water resources of northern Juab Valley, Utah,, by L. J. Bjorklund, U. S. Geological Survey, 1968.

No. 18. Hydrologic reconnaisssance of Skull Valley, Tooele County, Utah by J. W. Hood and K. M. Waddell, U. S. Geological Survey, 1968.

No. 19. An appraisal of the quality of surface water in the Sevier Lake basin, Utah, by D. C. Hahl and J. C. Mundorff, U.S. Geological Survey, 1968.

No. 20. Extensions of streamflow records in Utah, by J. K. Reid, L. E. Carroon, and G. E. Pyper, U.S. Geological Survey, 1969.

No. 21. Summary of maximum discharges in Utah streams, by G. L. Whitaker, U.S. Geological Survey, 1969.

No. 22. Reconnaissance of the ground-water resources of the upper Fremont River valley, Wayne County, Utah, by L. J. Bjorklund, U. S. Geological Survey, 1969.

No. 23. Hydrologic reconnaissance of Rush Valley, Tooele County, Utah, by J. W. Hood, Don Price, and K. M. Waddell, U.S. Geological Survey, 1969.

No. 24. Hydrologic reconnaissance of Deep Creek valley, Tooele and Juab Counties, Utah, and Elko and White Pine Counties, Nevada, by J. W. Hood and K. M. Waddell, U.S. Geological Survey, 1969.

No. 25. Hydrologic reconnaissance of Curlew Valley, Utah and Idaho, by E. L. Bolke and Don Price, U.S. Geological Survey, 1969.

No. 26. Hydrologic reconnaissance of the Sink Valley area, Tooele and Box Elder Counties, Utah, by Don Price and E. L. Bolke, U.S. Geological Survey, 1970.

No. 27. Water resources of the Heber-Kamas-Park City area, north-central Utah, by C. H. Baker, Jr., U.S. Geological Survey, 1970.

No. 28. Ground-water conditions in southern Utah Valley and Goshen Valley, Utah, by R. M. Cordova, U.S. Geological Survey, 1970.

No. 29. Hydrologic reconnaissance of Grouse Creek valley, Box Elder County, Utah, by J. W. Hood and Don Price, U.S. Geological Survey, 1970.

No. 30. Hydrologic reconnaissance of the Park Valley area, Box Elder County, Utah, by J. W. Hood, U.S. Geological Survey, 1971.

No. 31. Water resources of Salt Lake County, Utah, by A. G. Hely, R. W. Mower, and C. A. Harr, U.S. Geological Survey, 1971.

No. 32. Geology and water resources of the Spanish Valley area, Grand and San Juan Counties, Utah, by C. T. Sumsion, U.S. Geological Survey, 1971.

No. 33. Hydrologic reconnaissance of Hansel Valley and northern Rozel Flat, Box Elder County, Utah, by J. W. Hood, U.S. Geological Survey, 1971.

No. 34. Summary of water resources of Salt Lake County, Utah, by A. G. Hely, R. W. Mower, and C. A. Harr, U.S. Geological Survey, 1971.

No. 35. Ground-water conditions in the East Shore area, Box Elder, Davis, and Weber Counties, Utah, 1960-69, by E. L. Bolke and K. M. Waddell, U.S. Geological Survey, 1972.

No. 36. Ground-water resources of Cache Valley, Utah and Idaho, by L. J. Bjorklund and L. J. McGreevy, U.S. Geological Survey, 1971.

No. 37. Hydrologic reconnaissance of the Blue Creek Valley area, Box Elder County, Utah, by E. L. Bolke and Don Price, U.S. Geological Survey, 1972.

No. 38. Hydrologic reconnaissance of the Promontory Mountains area, Box Elder County, Utah, by J. W. Hood, U.S. Geological Survey, 1972.

No. 39. Reconnaissance of chemical quality of surface water and fluvial sediment in the Price River Basin, Utah, by J. C. Mundorff, U.S. Geological Survey, 1972.

No. 40. Ground-water conditions in the central Virgin River basin, Utah, by R. M. Cordova, G. W. Sandberg, and Wilson McConkie, U.S. Geological Survey, 1972.

No. 41. Hydrologic reconnaissance of Pilot Valley, Utah and Nevada, by J. C. Stephens and J. W. Hood, U.S. Geological Survey, 1973.

No. 42. Hydrologic reconniassance of the northern Great Salt Lake Desert and summary hydrologic reconnaissance of northwestern Utah, by J. C. Stephens, U.S. Geological Survey, 1973.

No. 43. Water resources of the Milford area, Utah, with emphasis on ground water, by R. W. Mower and R. M. Cordova, U.S. Geological Survey, 1974.

No. 44. Ground-water resources of the lower Bear River drainage basin, Box Elder County, Utah, by L. J. Bjorklund and L. J. McGreevy, U.S. Geological Survey, 1974.

No. 45. Water resources of the Curlew Valley drainage basin, Utah and Idaho, by C. H. Baker, Jr., U.S. Geological Survey, 1974.

No. 46. Water-quality reconnaissance of surface inflow to Utah Lake, by J. C. Mundorff, U.S. Geological Survey, 1974.

No. 47. Hydrologic reconnaissance of the Wah Wah Valley drainage basin, Millard and Beaver Counties, Utah, by J. C. Stephens, U.S. Geological Survey, 1974.

No. 48. Estimating mean streamflow in the Duchesne River basin, Utah, by R. W. Cruff, U.S. Geological Survey, 1974.

No. 49. Hydrologic reconnaissance of the southern Uinta Basin, Utah and Colorado, by Don Price and L. L. Miller, U.S. Geological Survey, 1975.

No. 50. Seepage study of the Rocky Point Canal and the Grey Mountain-Pleasant Valley Canal systems, Duchesne County, Utah, by R. W. Cruff and J. W. Hood, U.S. Geological Survey, 1976.

No. 51. Hydrologic reconnaissance of the Pine Valley drainage basin, Millard, Beaver, and Iron Counties, Utah, by J. C. Stephens, U.S. Geological Survey, 1976.

No. 52. Seepage study of canals in Beaver Valley, Beaver County, Utah, by R. W. Cruff and R. W. Mower, U.S. Geological Survey, 1976.

No. 53. Characteristics of aquifers in the northern Uinta Basin area, Utah and Colorado, by J. W. Hood, U.S. Geological Survey, 1976.

No. 54. Hydrologic evaluation of Ashley Valley, northern Uinta Basin area, Utah, by J. W. Hood, U.S. Geological Survey, 1977.

No. 55. Reconnaissance of water quality in the Duchesne River basin and some adjacent drainage areas, Utah, by J. C. Mundorff, U.S. Geological Survey, 1977.

No. 56. Hydrologic reconnaissance of the Tule Valley drainage basin, Juab and Millard Counties, Utah, by J. C. Stephens, U.S. Geological Survey, 1977.

No. 57. Hydrologic evaluation of the upper Duchesne River valley, northern Uinta Basin area, Utah, by J. W. Hood, U.S. Geological Survey, 1977.

No. 58. Seepage study of the Sevier Valley-Piute Canal, Sevier County, Utah, by R. W. Cruff, U.S. Geological Survey, 1977.

No. 59. Hydrologic reconnaissance of the Dugway Valley-Government Creek area, west-central Utah, by J. C. Stephens and C. T. Sumsion, U.S. Geological Survey, 1978.

No. 60. Ground-water resources of the Parowan-Cedar City drainage basin, Iron County, Utah, by L. J. Bjorklund, C. T. Sumsion, and G. W. Sandberg, U.S. Geological Survey, 1978.

No. 61. Ground-water conditions in the Navajo Sandstone in the central Virgin River basin, Utah, by R. M. Cordova, U.S. Geological Survey, 1978.

No. 62. Water resources of the northern Uinta Basin area, Utah and Colorado, with special emphasis on ground-water supply, by J. W. Hood and F. K. Fields, U.S. Geological Survey, 1978.

No. 63. Hydrology of the Beaver Valley area, Beaver County, Utah, with emphasis on ground water, by R. W. Mower, U.S. Geological Survey, 1978.

No. 64. Hydrologic reconnaissance of the Fish Springs Flat area, Tooele, Juab, and Millard Counties, Utah, by E. L. Bolke and C. T. Sumsion, U.S. Geological Survey, 1978.

No. 65. Reconnaissance of chemical quality of surface water and fluvial sediment in the Dirty Devil River basin, Utah, by J. C. Mundorff, U.S. Geological Survey, 1978.

No. 66. Aquifer tests of the Navajo Sandstone near Caineville, Wayne County, Utah, by J. W. Hood and T. W. Danielson, U.S. Geological Survey, 1979.

No. 67. Seepage study of the West Side and West Canals, Box Elder County, Utah, by R. W. Cruff, U.S. Geological Survey, 1980.

No. 68. Bedrock aquifers in the lower Dirty Devil River basin area, Utah, with special emphasis on the Navajo Sandstone, by J. W. Hood and T. W. Danielson, U.S. Geological Survey, 1980.

No. 69. Ground-water conditions in Tooele Valley, Utah, 1976-78, by A. C. Razem and J. I. Steiger, U.S. Geological Survey, 1980.

No. 70. Ground-water conditions in the Upper Virgin River and Kanab Creek basins area, Utah, with emphasis on the Navajo Sandstone, by R. M. Cordova, U.S. Geological Survey, 1981.

No. 71. Hydrologic reconnaissance of the Southern Great Salt Lake Desert and summary of the hydrology of West-Central Utah, by Joseph S. Gates and Stacie A. Kruer, U.S. Geological Survey, 1980.

No. 72. Reconnaissance of the quality of surface water in the San Rafael River basin, Utah, by J. C. Mundorff and Kendall R. Thompson, U.S. Geological Survey, 1982.

No. 73. Hydrology of the Beryl-Enterprise area, Escalante Desert, Utah, with emphasis on ground water, by R. W. Mower, U.S. Geological Survey, 1982.

No. 74. Seepage study of the Sevier River and the Central Utah, McIntyre, and Leamington Canals, Juab and Millard Counties, Utah, by L. R. Herbert, R. W. Cruff, Walter F. Holmes, U.S. Geological Survey, 1982.

No. 75. Consumptive use and water requirements for Utah, by A. Leon Huber, Frank W. Haws, Trevor C. Hughes, Jay M. Bagley, Kenneth G. Hubbard, and E. Arlo Richardson, 1982.

No. 76. Reconnaissance of the quality of surface water in the Weber River basin, Utah, by Kendall R. Thompson, U.S. Geological Survey, 1983.

No. 77. Ground-water reconnaissance of the central Weber River area, Morgan and Summit Counties, Utah, Joseph S. Gates, Judy I. Steiger, and Ronald T. Green, U.S. Geological Survey, 1984.

No. 78. Bedrock aquifers in the northern San Rafael Swell area, Utah, with special emphasis on the Navajo Sandstone, J. W. Hood and D. J. Patterson, U.S. Geological Survey, 1984.

No. 79. Ground-water hydrology and projected effects of ground-water withdrawals in the Sevier Desert, Utah, W. F. Holmes, 1984.

No. 80. Ground-water resources of northern Utah Valley, Utah, D. W. Clark and C. L. Appel, 1985.

No. 81. Ground-water conditions in the Kaiparowits Plateau area, Utah and Arizona, with emphasis on the Navajo Sandstone, Paul J. Blanchard, 1986.

No. 82. Seepage study of six Canals in Salt Lake County, Utah, L. R. Herbert, R. W. Cruff, and K. M. Waddell, 1985.

No. 83. Reconnaissance of the quality of surface water in the upper Virgin River Basin, Utah, Arizona, and Nevada, 1981-82, G. W. Sandberg and L. G. Sultz, 1985.

No. 84. Ground water conditions in the Lake Powell area, Utah, P. J. Blanchard, 1986.

WATER CIRCULARS

No. 1. Ground water in the Jordan Valley, Salt Lake County, Utah, by Ted Arnow, U.S. Geological Survey, 1965.

No. 2. Ground water in Tooele Valley, Utah, by J. S. Gates and O. A. Keller, U.S. Geological Survey, 1970.

BASIC-DATA REPORTS

*No. 1. Records and water-level measurements of selected wells and chemical analyses of ground water, East Shore area, Davis, Weber, and Box Elder Counties, Utah, by R. E. Smith, U.S. Geological Survey, 1961.

No. 2. Records of selected wells and springs, selected drillers' logs of wells, and chemical analyses of ground and surface waters, northern Utah Valley, Utah County, Utah, by Seymour Subitzky, U.S. Geological Survey, 1962.

No. 3. Ground-water data, central Sevier Valley, parts of Sanpete, Sevier, and Piute Counties, Utah, by C. H. Carpenter and R. A. Young, U.S. Geological Survey, 1963.

*No. 4. Selected hydrologic data, Jordan Valley, Salt Lake County, Utah, by I. W. Marine and Don Price, U.S. Geological Survey, 1963.

*No. 5. Selected hydrologic data, Pavant Valley, Millard County, Utah, by R. W. Mower, U.S. Geological Survey, 1963.

*No. 6. Ground-water data, parts of Washington, Iron, Beaver, and Millard Counties, Utah, by G. W. Sandberg, U.S. Geological Survey, 1963.

No. 7. Selected hydrologic data, Tooele Valley, Tooele County, Utah, by J. S. Gates, U.S. Geological Survey, 1963.

No. 8. Selected hydrologic data, upper Sevier River basin, Utah, by C. H. Carpenter, G. B. Robinson, Jr., and L. J. Bjorklund, U.S. Geological Survey, 1964.

*No. 9. Ground-water data, Sevier, Desert, Utah, by R. W. Mower and R. D. Feltis, U.S. Geological Survey, 1964.

No. 10. Quality of surface water in the Sevier Lake basin, Utah, by D. C. Hahl and R. E. Cabell, U.S. Geological Survey, 1965.

*No. 11. Hydrologic and climatologic data, collected through 1964, Salt Lake County, Utah, by W. V. Iorns, R. W. Mower, and C. A. Horr, U.S. Geological Survey, 1966.

No. 12. Hydrologic and climatologic data, 1965, Salt Lake County, Utah, by W. V. Iorns, R. W. Mower, and C. A. Horr, U.S. Geological Survey, 1966.

No. 13. Hydrologic and climatologic data, 1966, Salt Lake County, Utah, by A. G. Hely, R. W. Mower, and C. A. Horr, U.S. Geological Survey, 1967.

No. 14. Selected hydrologic data, San Pitch River drainage basin, Utah, by G. B. Robinson, Jr., U.S. Geological Survey, 1968.

No. 15. Hydrologic and climatologic data, 1967, Salt Lake County, Utah, by A. G. Hely, R. W. Mower, and C. A. Horr, U.S. Geological Survey, 1968.

No. 16. Selected hydrologic data, southern Utah and Goshen Valleys, Utah, by R. M. Cordova, U.S. Geological Survey, 1969.

No. 17. Hydrologic and climatologic data, 1968, Salt Lake County, Utah, by A. G. Hely, R. W. Mower, and C. A. Horr, U.S. Geological Survey, 1969.

No. 18. Quality of surface water in the Bear River basin, Utah, Wyoming, and Idaho, by K. M. Waddell, U.S. Geological Survey, 1970.

No. 19. Daily water-temperature records for Utah streams, 1944-68, by G. L. Whitaker, U.S. Geological Survey, 1970.

No. 20. Water-quality data for the Flaming Gorge area, Utah and Wyoming, by R. J. Madison, U.S. Geological Survey, 1970.

No. 21. Selected hydrologic data, Cache Valley, Utah and Idaho, by L. J. McGreevy and L. J. Bjorklund, U.S. Geological Survey, 1970.

No. 22. Periodic water- and air-temperature records for Utah streams, 1966-70, by G. L. Whitaker, U.S. Geological Survey, 1971.

No. 23. Selected hydrologic data, lower Bear River drainage basins, Box Elder County, Utah, by L. J. Bjorklund and L. J. McGreevy, U.S. Geological Survey, 1973.

No. 24. Water-quality data for the Flaming Gorge Reservoir area, Utah and Wyoming, 1969-72, by E. L. Bolke and K. M. Waddell, U.S. Geological Survey, 1972.

No. 25. Streamflow characteristics in northeastern Utah and adjacent areas, by F. K. Fields, U.S. Geological Survey, 1975.

No. 26. Selected hydrologic data, Uinta Basin area, Utah and Colorado, by J. W. Hood, J. C. Mundorff, and Don Price, U.S. Geological Survey, 1976.

No. 27. Chemical and physical data for the Flaming Gorge Reservoir area, Utah and Wyoming, by E. L. Bolke, U.S. Geological Survey, 1976.

No. 28. Selected hydrologic data, Parowan Valley and Cedar City Valley drainage basins, Iron County, Utah, by L. J. Bjorklund, C. T. Sumsion, and G. W. Sandberg, U.S. Geological Survey, 1977.

No. 29. Climatologic and hydrologic data, southeastern Uinta Basin, Utah and Colorado, water years 1975 and 1976, by L. S. Conroy and F. K. Fields, U.S. Geological Survey, 1977.

No. 30. Selected ground-water data, Bonneville Salt Flats and Pilot Valley, western Utah, by G. C. Lines, U.S. Geological Survey, 1977.

No. 31. Selected hydrologic data, Wasatch Plateau-Book Cliffs coal-fields area, Utah, by K. M. Waddell and others, U.S. Geological Survey, 1978.

No. 32. Selected coal-related ground-water data, Wasatch Plateau-Book Cliffs area, Utah, by C. T. Sumsion, U.S. Geological Survey, 1979.

No. 33. Hydrologic and climatologic data, southeastern Uinta Basin, Utah and Colorado, water year 1977, by L. S. Conroy, U.S. Geological Survey, 1979.

No. 34. Hydrologic and climatologic data, southeastern Uinta Basin, Utah and Colorado, water year 1978, by L. S. Conroy, U.S. Geological Survey, 1980.

No. 35. Ground-water data for the Beryl-Enterprise area, Escalante Desert, Utah, by R. W. Mower, U.S. Geological Survey, 1981.

No. 36. Surface-water and climatologic data, Salt Lake County, Utah, Water Year 1980, by G. E. Pyper, R. C. Christensen, D. W. Stephens, H. F. McCormack, and L. S. Conroy, U.S. Geological Survey, 1981.

No. 37. Selected ground-water data, Sevier Desert, Utah, 1935-82, by Michael Enright and Walter F. Holmes, U.S. Geological Survey, 1982.

No. 38. Selected hydrologic data, Price River Basin, Utah, water years 1979 and 1980, by K. M. Waddell, J. E. Dodge, D. W. Darby, and S. M. Theobald, U.S. Geological Survey, 1982.

No. 39. Selected hydrologic data for Northern Utah Valley, Utah, 1935-82, by Cynthia L. Appel, David W. Clark, and Paul E. Fairbanks, U.S. Geological Survey, 1982.

No. 40. Surface water and climatologic data, Salt Lake County, Utah, water year 1981, with selected data for water years 1980 and 1982, by H. F. McCormack, R. C. Christensen, D. W. Stephens, G. E. Pyper, J. F. Weigel, and L. S. Conroy, U.S. Geological Survey, 1983.

No. 41. Selected hydrologic data, Kolob-Alton-Kaiparowits coal-fields area, south-central Utah, by Gerald G. Plantz, U.S. Geological Survey, 1983.

No. 42 Streamflow characteristics of the Colorado River Basin in Utah through September 1981, R. C. Christensen, E. B. Johnson, and G. G. Plantz (n preparation).

No. 43 Selected well data from the MX-missile siting study, Tooele, Juab, Millard, Beaver, and Iron Counties, Utah, James L. Mason, John W. Atwood, and Priscilla S. Beuttner.

INFORMATION BULLETINS

*No. 1. Plan of work for the Sevier River Basin (Sec. 6, P. L. 566), U.S. Department of Agriculture, 1960.

*No. 2. Water production from oil wells in Utah, by Jerry Tuttle, Utah State Engineer's Office, 1960.

*No. 3. Ground-water areas and well logs, central Sevier Valley, Utah, by R. A. Young, U.S. Geological Survey, 1960.

*No. 4. Ground-water investigations in Utah in 1960 and reports published by the U.S. Geological Survey or the Utah State Engineer prior to 1960, by H. D. Goode, U.S. Geological Survey, 1960.

*No. 5. Developing ground water in the central Sevier Valley, Utah, by R. A. Young and C. H. Carpenter, U.S. Geological Survey, 1961.

*No. 6. Work outline and report outline for Sevier River basin survey, (Sec. 6, P. L. 566), U.S. Department of Agriculture, 1961.

*No. 7. Relation of the deep and shallow artesian aquifers near Lynndyl, Utah, by R. W. Mower, U.S. Geological Survey, 1961.

*No. 8. Projected 1975 municipal water-use requirements, Davis County, Utah, by Utah State Engineer's Office, 1962.

No. 9. Projected 1975 municipal water-use requirements, Weber County, Utah, by Utah State Engineer's Office, 1962.

*No. 10. Effects on the shallow artesian aquifer of withdrawing water from the deep artesian aquifer near Sugarville, Millard County, Utah, by R. W. Mower, U.S. Geological Survey, 1963.

*No. 11. Amendments to plan of work and work outline for the Sevier River basin (Sec. 6, P. L. 566), U.S. Department of Agriculture, 1964.

*No. 12. Test drilling in the upper Sevier River drainage basin, Garfield and Piute Counties, Utah, by R. D. Feltis and G. B. Robinson, Jr., U.S. Geological Survey, 1963.

*No. 13. Water requirements of lower Jordan River, Utah, by Karl Harris, Irrigation Engineer, Agricultural Research Service, Phoenix, Arizona, prepared under informal cooperation approved by Mr. W. W. Donnan, Chief, Southwest Branch (Riverside, California) Soil and Water Conservation Research Division, Agricultural Research Service, U.S.D.A., and by W. D. Criddle, State Engineer, State of Utah, Salt Lake City, Utah, 1964.

*No. 14. Consumptive use of water by native vegetation and irrigated crops in the Virgin River area of Utah, by W. D. Criddle, J. M. Bagley, R. K. Higginson, and D. W. Hendricks, through cooperation of Utah Agricultural Experiment Station, Agricultural Research Service, Soil and Water Conservation Branch, Western Soil and Water Management Section, Utah Water and Power Board, and Utah State Engineer, Salt Lake City, Utah, 1964.

*No. 15. Ground-water conditions and related water-administration problems in Cedar City Valley, Iron County, Utah, February, 1966, by J. A. Barnett and F. T. Mayo, Utah State Engineer's Office.

*No. 16. Summary of water well drilling activities in Utah, 1960 through 1965, compiled by Utah State Engineer's Office, 1966.

*No. 17. Bibliography of U.S. Geological Survey water-resources reports for Utah, compiled by O. A. Keller, U.S. Geological Survey, 1966.

*No. 18. The effect of pumping large-discharge wells on the ground-water reservoir in southern Utah Valley, Utah County, Utah, by R. M. Cordova and R. W. Mower, U.S. Geological Survey, 1967.

No. 19. Ground-water hydrology of southern Cache Valley, Utah, by L. P. Beer, Utah State Engineer's Office, 1967.

*No. 20. Fluvial sediment in Utah, 1905-65, A data compilation by J. C. Mundorff, U.S. Geological Survey, 1968.

*No. 21. Hydrogeology of the eastern portion of the south slopes of the Uinta Mountains, Utah, by L. G. Moore and D. A. Barker, U.S. Bureau of Reclamation, and J. D. Maxwell and B. L. Bridges, Soil Conservation Service, 1971.

*No. 22. Bibliography of U.S. Geological Survey water-resources reports for Utah, compiled by B. A. LaPray, U.S. Geological Survey, 1972.

*No. 23. Bibliography of U.S. Geological Survey water-resources reports for Utah, compiled by B. A. LaPray, U.S. Geological Survey, 1975.

No. 24. A water-land use management model for the Sevier River Basin, Phase I and II, by V. A. Narasimham and Eugene K. Israelsen, Utah Water Research Laboratory, College of Engineering, Utah State University, 1975.

No. 25. A water-land use management model for the Sevier River Basin, Phase III, by Eugene K. Israelsen, Utah Water Research Laboratory, College of Engineering, Utah State University, 1976.

No. 26. Test drilling for fresh water in Tooele Valley, Utah, by K. H. Ryan, B. W. Nance, and A. C. Razem, Utah Department of Natural Resources, 1981.

No. 27. Bibliography of U.S. Geological Survey Water-Resources Reports for Utah, compiled by Barbara A. LaPray and Linda S. Hamblin, U.S. Geological Survey, 1980.

PUBLICATION NO. 84
PLATE 2